STABILIZATION OF A GRANULAR SOIL BY A MECHANICAL METHOD

by

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Eastern Colorado, as well as much of the Plains area of the Central United States, contains great quantities of mineral aggregate, unsuitable for use as a pavement construction material in its natural, unaltered state. Each year millions of dollars are spent on pavement construction in these regions requiring long haul distances of great quantities of suitable mineral aggregate or the use of costly admixtures.

This thesis is concerned with upgrading marginal cohesionless soils by altering the natural soil gradation through mechanical methods, thereby rendering otherwise unsuitable soils acceptable as pavement construction materials. The submarginal soil tested is classified as an A-2-4(0) soil according to the American Association of State Highway Officials' Classification Standards.

The aggregate used to modify the soil's gradation consisted of a pit run gravel, separated into its constitutent sizes by sieving. Clay was also added to some samples to change the soil's gradation.

Talbot's gradation formula was used as the basis for determining the quantity of aggregate to be added to the natural soil to achieve the required stability. Various percentages of large size aggregate were also added to the natural soil to achieve the required stability. The California Bearing Ratio test served as the criterion for determining stability requirements.

Addition of aggregate as required to satisfy Talbot's equation through a wide range of successive sizes did not prove to be as economical as the addition of 12 to 17 percent large size aggregate because of the larger amount of aggregate required to meet the same minimum desired strength and stability characteristics. Stabilization by this mechanical method can be more economical than stabilization by the least expensive admixtures, if, the haul distance and production costs are low.

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CHAPTER I

INTRODUCTION

Mechanical stabilization of a granular soil is the physical process of improving soil properties by the addition to, or removal from, the soil different amounts of various grain size material, thereby changing the soil gradation.

Soil stabilization is practiced in areas where a limited supply of quality aggregate exists and when it is economically feasible to upgrade otherwise unsuitable materials for use in pavement construction. In eastern Colorado quality mineral aggregate sources are confined to the two main river systems (the South Platte and the Arkansas Rivers and their tributaries) in the forms of sand and gravel. Suitable bedrock formations which can be processed economically and practically, do not exist, (25, pg. 10-11). Therefore, in order to conserve quality aggregate for more important projects, reduce aggregate transportation costs and still construct superior highways, the upgrading of substandard materials is necessary.

Granular soil stabilization is accomplished by many methods. This paper is confined to mechanical means of stabilization by investigating the results of the addition of different amounts and sizes of mineral aggregate to the natural soil.

When considering a mechanical means of stabilization, the amount and sizes of the material to be added to achieve the desired properties are the most important factors to be determined. A.N. Talbot (19) has advanced a formula for the gradation of soil aggregate to achieve a maximum density, which is based on the percentage by weight of material passing any standard size sieve. Talbot's formula is

$p=(d/D)^n$, where;

p= the percent by weight finer than particle size 'd';

d= any size particle in the soil sample;

D= maximum size particle in the soil sample;

n= a numerical exponent or gradation index, the optimum value being that which gives maximum density.

The merits and limitations of the formula for use in granular soil stabilization, based on the findings of this paper, are discussed in Chapter IX.

The testing procedure used to determine the amount and sizes of aggregate required to improve the original soil properties, thereby achieving a more stable soil gradation, included the following;

1. testing the original soil (unaltered) for maximum density and strength characteristics, as determined by the California Bearing Ratio (CBR) test;

2. altering the soil gradation according to Talbot's formula for the entire range of particle sizes within the soil and testing the altered soil for maximum density and strength characteristics, as determined by the CBR test;

3. determining the effects on stability of the various sizes within the soil's gradation by omitting certain size particles from the range of sizes added to satisfy Talbot's equation and observing the changes in maximum density and strength, as determined by the CBR test;

4. changing the soil gradation by adding different percentages of particles larger than the maximum size particle occurring in the

original material and testing the resulting gradations for maximum density and strength by the CBR test method.

Results from the above tests would then indicate the amount and sizes of aggregate to be added to obtain the desired degree of stability. The required properties and those desired for soil-aggregate mixtures for use in pavement construction are described in Chapter III.

The soil used for this study is classified as a silty sand, A-2-4(0), which is found in eastern Colorado. Chapters V, VI, and VII describe the location and geology of the deposit, the classification, identification and mineral composition and the physical properties of the silty sand used for the study.

Although the soil used in this project was located in Arapahoe County, Colorado, it is felt that this information and experience can readily be applied to similar soils in other areas and produce similar results.

CHAPTER II

GENERAL PROPERTIES OF GRANULAR SOILS

Definition

Granular soil is generally considered to be composed of a mixture of aggregate and binder; the aggregate being the bulky portion of the mixture retained on a No. 200 sieve, while the binder is the finer portion that passes this sieve. The relative amounts of binder to aggregate determine the soil properties.

Stability

The stability of a soil-aggregate mixture depends on the grain-size distribution, particle shape, relative density, internal friction, and cohesion,(28, pg. 284). Granular materials exhibiting a high degree of stability possess high internal friction to resist deformation under load, the proper amount of binder material to provide cohesion to hold the particles together to reduce particle slippage, and a grain-size distribution that provides a high density when compacted.

High internal friction is obtained when rough, angular particles are compacted to a high density, establishing many grain-to-grain contacts.

Density and Permeability

The density of a granular soil depends primarily on the gradation of the aggregate and the amount of binder present in the sample. If the soil gradation contains particles of one size, the void space will be large and the density low. If the soil contains particles of all sizes the void space will be small, but the density will be high. Thus there appears to be an optimum gradation which will give

the right amount of each size particle to produce the smallest amount of void space. Talbot's equation is an attempt to determine the optimum gradation which will give maximum density.

The permeability of a granular soil depends on the grain-size distribution, type of coarse aggregate, type of binder, and density of the soil, (28, pg. 290). Since permeability is the ability of water to flow through the soil, the amount of void space and hence lack of binder is important in determining soil permeability. Generally, as the density increases, the permeability decreases.

Compaction

Compaction is the process of decreasing the soil void space by forcefully removing entrapped air thereby increasing soil density. The effectiveness of any compactive effort depends on the moisture content of the soil at the time of compaction. Testing experience has shown that there is an optimum moisture content at which maximum soil density develops. If a granular soil is compacted at a moisture content less than optimum, the soil stability is greatly reduced with soaking. If the soil is compacted at a higher moisture content than optimum, soil settling takes place when the sample is soaked. Therefore, compaction at optimum moisture content is desirable in order to give the greatest density and maximum stability when subjected to service.

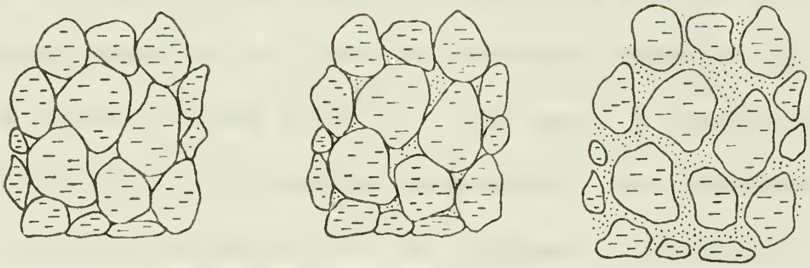
Plasticity and Durability

Plastic soils are those which have the ability to be remolded or reworked without fracturing, usually accompanied by a volume change. A volume change is highly undesirable for a soil-aggregate mixture

once it is placed in the pavement structure. Granular soils are generally non-plastic. The addition of a binder may produce a small range of plasticity in a granular soil. If the binder is greatly affected by a moisture change, such as in the case of a clay material, the grain-to-grain content of the aggregate may be destroyed resulting in a reduction of soil-aggregate stability. Therefore, the properties of the binder and the amount present must be carefully controlled in order to reduce the possibility of an excessive volume change with variation in moisture content.

Since strength to resist load is achieved through the grain-to-grain contact of the aggregate, the durability or resistance to fracture of the aggregate must be high. Aggregates subjected to movement must be durable enough to withstand particle abrasion.

Thus, the physical state and desired properties of a granular soil are determined by the optimum gradation, aggregate durability, binder cohesion, and optimum moisture content at time of compaction. Figure 2.1 shows the possible physical states of soil-aggregate mixture and lists the properties of each.



(a)	(b)	(c)
(*a*) Aggregate with no fines	(*b*) Aggregate with Sufficient Fines for Maximum Density	(*c*) Aggregate with Great Amount of Fines
Grain-to-grain contact	Grain-to-grain contact with increased resistance against deformation	Grain-to-grain contact destroyed, aggregate "floating" in soil
Variable density	Increased density	Decreased density
Pervious	Low permeability	Low permeability
Nonfrost susceptible	Frost susceptible	Frost susceptible
High stability if confined, low if unconfined	Relatively high stability in confined or unconfined conditions	Low stability
Not affected by adverse water condition	Not greatly affected by adverse water condition	Greatly affected by adverse water condition
Difficult to compact	Moderately difficult to compact	Not difficult to compact

Physical states of soil-aggregate mixtures.

Figure 2.1

*After Yoder (28, pg. 285)

CHAPTER III

REQUIRED PROPERTIES OF SOIL-AGGREGATE MIXTURES FOR USE IN PAVEMENT CONSTRUCTION

Granular soils are used in all components of pavement construction. The principal use of stabilized mixtures are for subbase, and base courses. Many of the required properties for the stabilized soil-aggregate mixture vary with the pavement component and the type of wearing surface placed above it. Yet, many of the desired properties are required by all pavement components. Most specifications state in detail requirements for the aggregate durability, soil-aggregate gradation, and the degree of compaction to be achieved.

In the Standard Specification for Materials for Soil-Aggregate Subbase, Base and Surface Courses (AASHO M147-57) of the American Association of State Highway Officials (AASHO) the following aggregate requirements are specified:

> "2. (a) Coarse aggregate retained on the No. 10 sieve shall consist of hard, durable particles of fragments of stone, gravel or slag. Materials that break up when alternately frozen and thawed or wetted and dried shall not be used.
> (b) Coarse aggregate shall have a percentage of wear, by the Los Angles test, of not more than 50.
> 3. (a) Fine aggregate passing the No. 10 sieve shall consist of natural or crushed sand, and fine mineral particles passing the No.200 sieve.
> (b) The fraction passing the No.200 sieve shall not be greater than two-thirds of the fraction passing the No.40 sieve. The fraction passing the No.40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6.
> 4. The composite material shall be free from vegetable matter and lumps or balls of clay and shall conform to the grading requirements of Table I,"
> (1, pg.53).

Table 3.1 lists the grading requirements for soil-aggregate materials as specified by AASHO (Table I above).

Compactive effort is usually prescribed by the contracting agency at some percentage, 90% to 95% usually, of the Standard of Modified AASHO compaction, (AASHO T180-57).

The above soil-aggregate specifications are for aggregate that is to be used under any type of wearing surface. However, there are also certain required properties peculiar to each type of wearing surface placed upon the soil-aggregate foundation system.

If the soil-aggregate foundation supports a rigid concrete wearing surface, load carrying capacity is not the most important required function for the subbase. Soil-aggregate gradation is usually the most important requirement for rigid pavements since it has bearing on the degree of subgrade or subbase pumping and in establishing the drainage characteristics of the base course, (26, pg.16-30).

For flexible pavements, aggregate strength and stability are very important since the load is distributed to the subgrade through the base and subbase materials, (26, pg.16-30). Density and permeability of the compacted base must be such that drainage is possible in order to prevent frost heave, while the compacted base remains stable under water-flow conditions.

Soil-aggregate mixtures that serve as a wearing surface must contain enough soil binder to prevent the loosening of particles from the surface. The plasticity index and geometric characteristics of the aggregate are important factors that determine the wear-resistant forces of soil-aggregate surface courses, (14, pg.63).

TABLE 3.1

GRADING REQUIREMENTS FOR SOIL-AGGREGATE MATERIALS

Sieve Size	Percentage by weight passing square mesh sieve					
	Grading A	Grading B	Grading C	Grading D	Grading E	Grading F
2-inch	100	100	-	-	-	-
1-inch	-	75-95	100	100	100	100
3/8 inch	30-65	40-75	50-85	60-100	-	-
No. 4	25-55	30-60	35-65	50-85	55-100	70-100
No. 10	15-40	20-45	25-50	40-70	40-100	55-100
No. 40	8-20	15-30	15-30	25-45	20-50	30-70
No. 200	2-8	5-20	5-15	5-20	6-20	8-25

AASHO Specifications (1, pg. 53)

For any wearing surface used, maximum stability is obtained by use of angular aggregate as opposed to excessive amounts of smooth, flat, laminated material such as shale, slate and schist. Aggregate used should have good freeze-thaw resistance, a low coefficient of expansion, and should be chemically inert, (11, pg. 338).

Soil-aggregate strength is generally determined from triaxial or California Bearing Ratio (CBR) tests. Most agencies concerned with pavement construction specify a minimum CBR value to be used for various pavement components. In many states design charts based on CBR value are used for determining pavement thickness.

Most construction agencies, including those of the federal government, require a CBR value of not less than 80 (after soaking) for base

course material underlying bituminous surfacing, with expansion of specimens, soaked for four days in a water bath, not to exceed 1%, (12, pg. 417-419). The pavement thickness design method used by the U.S. Navy Department specifies a minimum CBR value of 30, after soaking, for materials to be used as a subbase support under portland cement concrete pavements, (26, pg. 23-13).

CHAPTER IV

THE NATURE AND FUNCTION OF STABILIZATION

Definition

As stated in previous chapters, strength to resist deformation and stability under load are the most important characteristics of soil-aggregate mixtures for use in pavement foundations. Thus, a stabilized soil is one "exhibiting a marked and sustained resistance to deformation under repeated or continuing load application, whether in a wet or dry state," (26, pg. 21-7).

Tschebotarioff defines the process of stabilization as, "any artificial method employed for the purpose of improving by suitable regrading or by special admixtures, such properties of a soil as are important for the maintenance of the shearing strength and of the volume and shape of the soil," (22, pg. 311).

Therefore, soil stabilization implies the improvement of strength and resistance to deformation of a soil not exhibiting those properties in its natural state. This paper is primarily concerned with a mechanical or regrading stabilization method, but several types of admixture stabilization methods will be mentioned.

Factors Affecting Stability

As in any engineering undertaking, the economics of the problem, in view of the benefits derived, determine if the soil warrants stabilization. There are, however, factors peculiar to each soil that ultimately determine the economics of the stabilizing process.

Grain shape

Granular soils obtain their strength from internal friction of the particles. The more angular the particles the more internal

friction develops. Flat, smooth particles tend to slip over one-another and develop low internal friction. Experience has shown that for identical gradations, the CBR values for mixtures composed of angular particles are somewhat greater than for aggregates containing rounded pebbles, (28, pg. 287).

Grain-Size Distribution

Most granular soils achieve maximum stability when the aggregate is well graded. The amount of binder which adds stability thru cohesion is very important. Yoder, (28, pg. 286), reports that "maximum stability as measured by the CBR test resulted when about 6 to 8% of the material passed a #200 mesh sieve." This percentage of binder does not destroy the grain-to-grain contact of the particles. In general, maximum density occurs for well graded mixtures, with maximum stability occurring at moisture contents close to that for maximum density. Liquid limit and plasticity index are also functions of the fine material present. Most specifications for base course materials limit the value of the plasticity index to less than 6.

Moisture Content

The moisture content at the time of compaction should be close to optimum to insure the development of maximum density. Excessive moisture content is the major cause of instability. Most specifications limit moisture content at the time of compaction by specifying the density to be obtained.

Permeability

The permeability of a soil-aggregate mixture has a great effect on stability. If the mixture is too permeable, the fines are removed

by percolating water, removing soil cohesion. If the mixture is practically impervious, volume change due to swell and frost heave may occur.

Compaction

Adequate compaction of granular soils used for pavement construction minimizes consolidation and wearing surface-base separation. Uniform compaction and soil composition are necessary to avoid differential settlement and excessive stress concentration.

Stabilization Methods

Methods of stabilization are classified according to the process used to improve the soil. Mechanical stabilization improves aggregate-binder ratio through soil regrading or densification by means of compaction. Admixture stabilization changes soil properties through additives that act as cementing agents, water-proofing agents, water-retarding agents, water-retaining agents, and agents for special chemical purposes.

Compaction increases internal friction by forcing the particles together thereby decreasing void space. Therefore, it is used in all types of stabilizing processes as a final step in pavement construction.

Mechanical stabilization is the improvement of soil properties by changing the soil gradation. Soil-aggregate gradation, from the standpoint of high density, can be represented by Talbot's equation, $p=100(d/D)^n$, where:

p= percentage by weight smaller than any particle; size d;
d= any particle size in the sample;
D= maximum particle size;
n= an exponent or gradation index;

Yoder reports that maximum density generally occurs when n=0.50, (28, pg. 286). The Bureau of Public Roads feel that a value of n=0.45 most nearly represents an ideal grading from the standpoint of density, (4, pg. 7).

CHAPTER V

LOCATION AND GEOLOGY OF TEST SOIL DEPOSIT

The parent material used in this report was taken from the A. C. Boss Pit, located in the northern half of Section 11, T4S, R61W, Arapahoe County, approximately three miles northeast of Byers, Colorado, (See fig. 5.1).

The pit is located within the Denver Basin, a geosynclinal basin formed from the accumulation of detritus, weathered and transported from the ancestral Rocky Mountains to the west, (25, pg. 10).

Topography

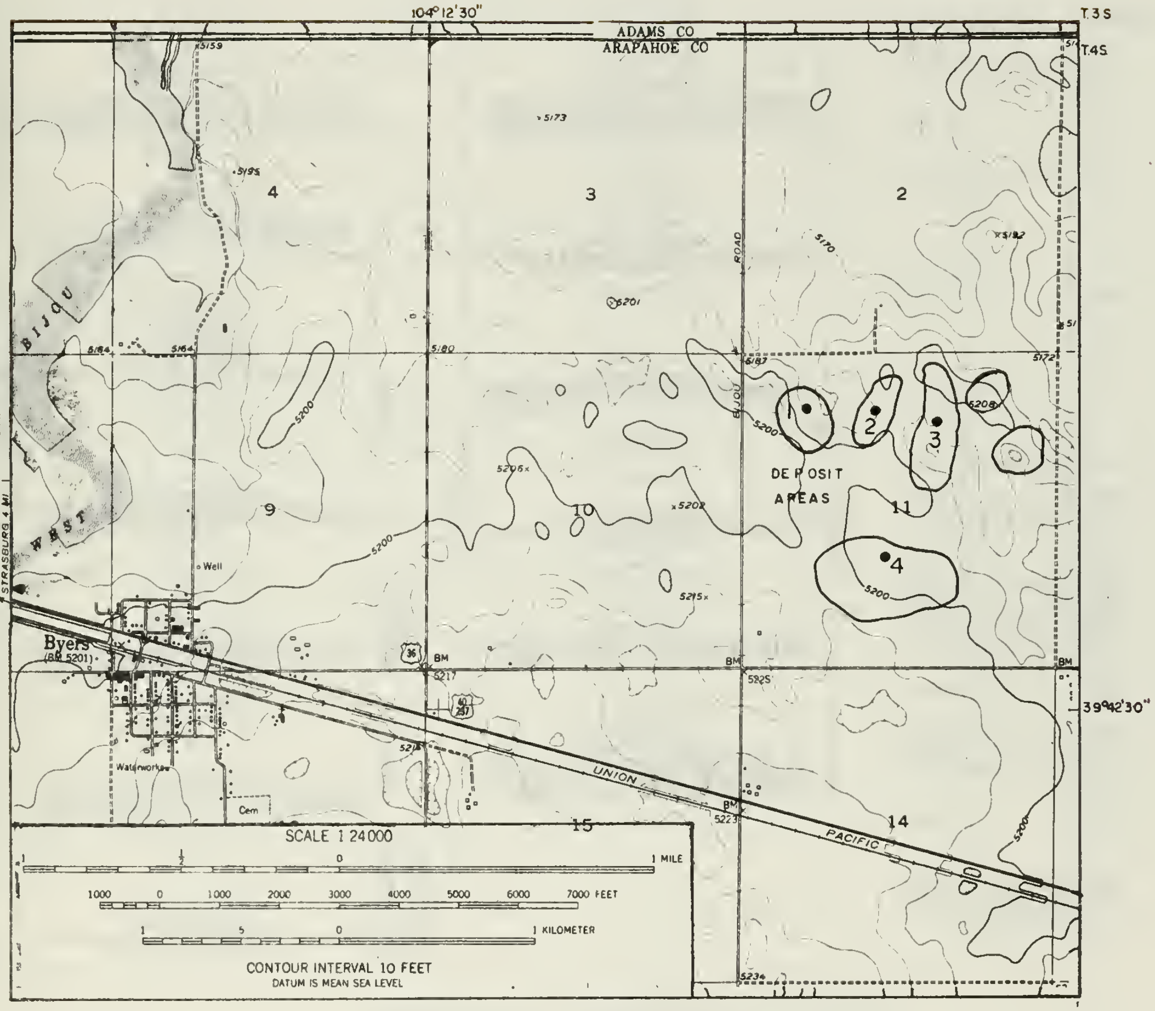
The topography of the plains area is that characteristic of recent sedimentary deposits of relatively easily eroded beds exposed to a semi-arid climate. It is a region of rolling relief, broad shallow valleys with gently sloping sides. The stream bottoms are wide and shallow, some with bordering terraces.

Bedrock

Chapter I indicated that bedrock suitable for practical and economic quarrying is non-existent in the area. A description of the underlying strata in the region indicates the validity of this statement. Figure 5.2 shows a general stratigraphic column indicating depth below the surface and rock type. As can be seen from the column, suitable materials (limestone particularly) occur in thin seams at relatively great depths.

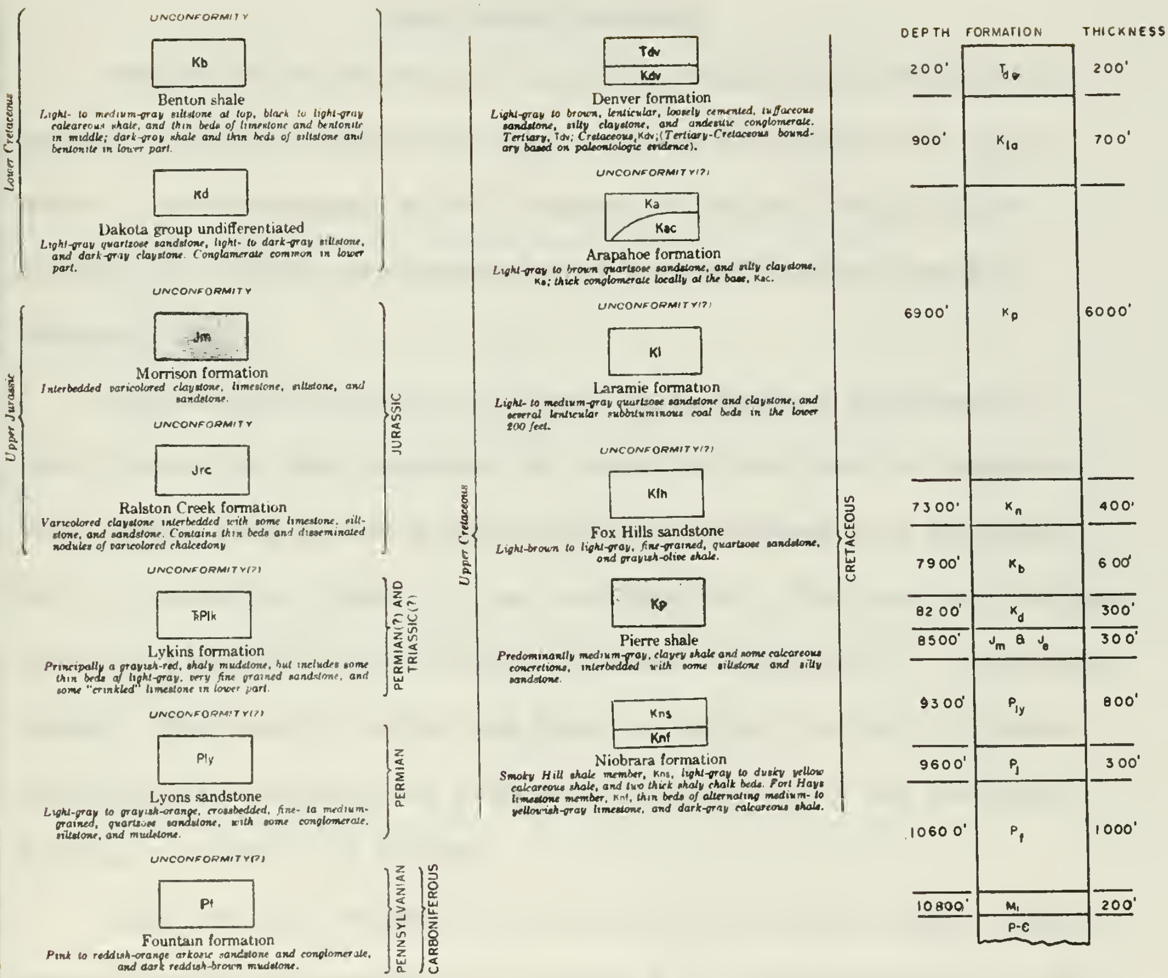
Surficial Deposits

The surficial deposits of the Byers area consist mainly of weathered material from the Denver and Arapahoe formations, with alluvium deposited in stream beds. The Denver Formation consists of



REGIONAL MAP

FIGURE 5.1



GENERALIZED STRATIGRAPHIC COLUMN

FIGURE 5.2

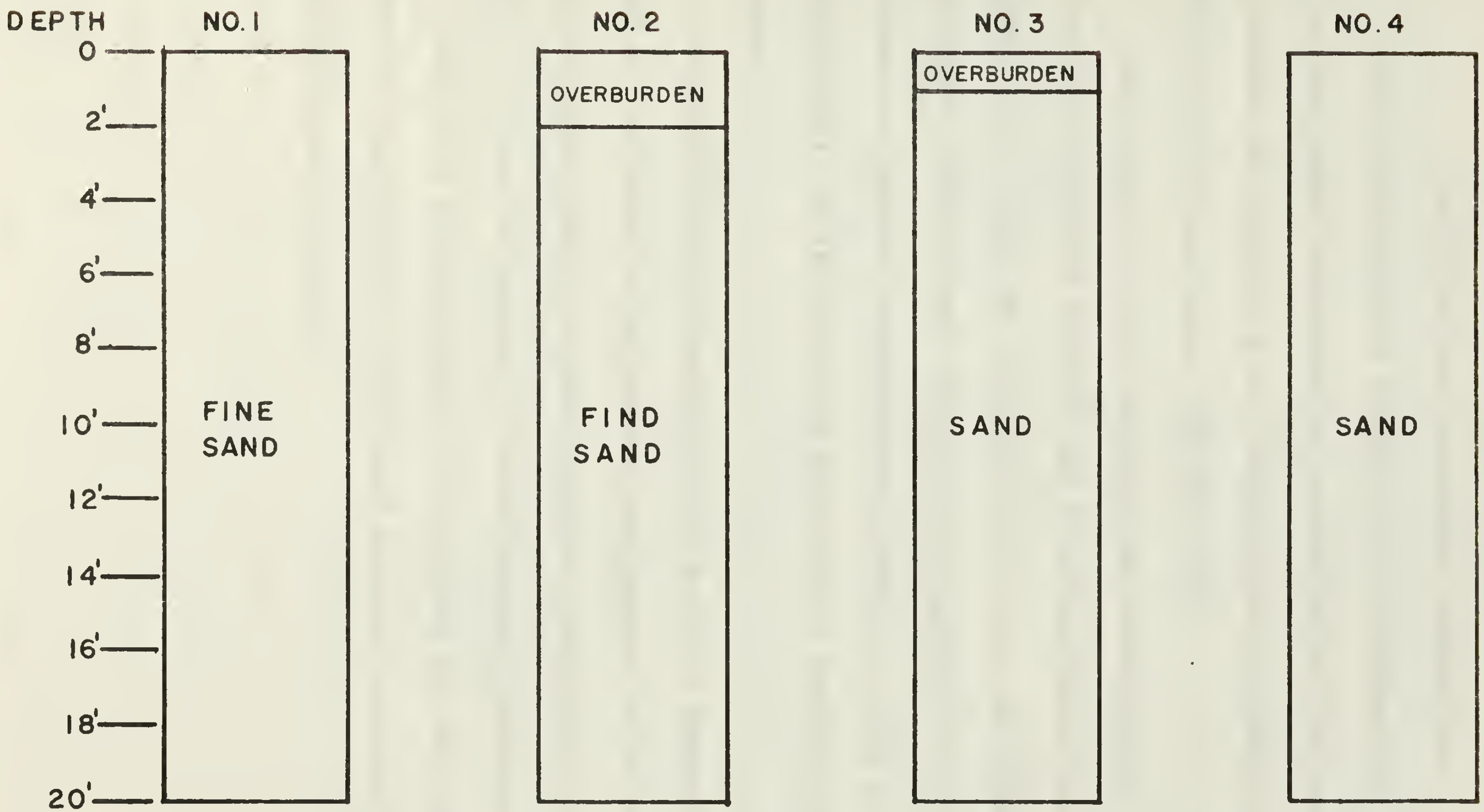
conglomerates with minor sand and clay minerals from older sediments, while the Arapahoe consists of clay with lenticular sandstones. The soil under study appears to be part of the sandy material of the Denver Formation.

Field Identification

Inspection of the deposit location revealed an undisturbed deposit presently covered by prairie grass and cultivated winter wheat. The topography of the location contained little relief leaving no exposed area where the soil stratification could be observed.

Data obtained from the Colorado State Highway Department's Field Report of 1960 verified the status of the Boss Pit Material. This report also included test hole data, obtained by a Williams Drill, from which figure 5.3 was constructed. The test hole Borings shown in figure 5.3 are located by number in figure 5.1. Since the Highway Department's report was made in conjunction with a reconnaissance type survey, the cost of drilling limited the test hole borings to a depth of 20 feet.

Since the soil deposit site was still privately owned, visual identification was confined to surface soil examination only. The surface soil observed appeared to contain a greater quantity of finer grained sand particles than that used in the laboratory tests. Recent deposition of fine grained material by the wind was thought to be the cause for the difference in the relative amounts of fine material present in the laboratory and field soil samples.



LOG of TEST-HOLE BORINGS

FIGURE 5.3

CHAPTER VI

TEST SOIL CLASSIFICATION, IDENTIFICATION, AND MINERAL COMPOSITION

A soil classification system is an arrangement of different soils into groups having similar properties for the purpose of estimating and predicting soil capabilities by association with soils whose properties are known, (18, pg. 102).

Classification of the test soil was determined by the standard laboratory grain-size analysis and Atterberg Limits tests, (See Chapter VII). Since the interest in this soil was primarily for use in pavement construction, the soil was classified by those systems pertinent to pavement construction. Table 6.1 lists the classification results of the test soil according to specific classification systems.

The mineralogical composition and particle shapes were determined by the author by microscopic examination of the constituent soil particles, which had been separated previously by sieve analysis. Table 6.2 lists the results of the microscopic examination.

Results of the laboratory test indicate the soil under study should be classified as a silty-sand material composed primarily of subangular quartz grains.

TABLE 6.1

SOIL CLASSIFICATION

Classification System	Basic Type	Results
AASHO (M145-49) (1, pg. 37)	Atterberg Limits and Grain-Size	A-2-4(0)
Unified (18, pg. 105)	Atterberg Limits and Grain-Size	SM-Silty Sand
CAA (18, pg. 106)	Plasticity and Grain-Size	E-3
U. S. Department of Agriculture (USDA) Textural Classification (13, pg. 61)	Grain-Size	Sand
Cassagrande (18, pg. 106)	Plasticity and Grain-Size	SF
Colorado State Highway Department (5, pg. 13)	(AASHO)	A-2-4(0)

TABLE 6.2

MINERAL COMPOSITION

Particle Size*	Minerals	Grain Shape	Note
- 4+ 8	Frosted Quartz Few Chert Grains	Rounded	Primarily Organic Material
- 8+ 16	Clear Quartz Some Feldspars	Subangular	Some Organic Material
-16+ 30	Quartz with very little feldspars	Subangular	
-30+ 50	Quartz	Subangular	
-50+100	Quartz and Fine Chert	Subangular	
-200**	Silt and Clay		

*Standard Sieve Sizes **From Hydrometer Analysis

CHAPTER VII

LABORATORY PROCEDURE AND TEST RESULTS

Sampling and Sample Preparation

The materials used in the tests were surveyed and sampled by the Colorado State Highway Department. Thereafter, representative materials were placed in large containers and delivered to the University of Colorado Soils Laboratory where they were allowed to air dry for some time.

Samples were taken from different containers and at different levels within each container and subjected to sieve analysis in order to insure that representative samples were used in each test. The samples yielded similar grain-size distributions. Therefore, it was assumed that any separation which took place within the containers was minor and that all subsequent samples were representative of the native soil.

All samples used for testing the physical properties, for the mechanical analysis, and for the compaction tests were prepared in accordance with AASHO specifications (T87-49) - Standard Method of Dry Preparation of Disturbed Soil Samples for Test, (1, pg. 273).

Testing Program

The method of testing used to determine the effect of the different amounts and sizes of aggregate added to stabilize the soil was based on four procedures. First, the original soil's grain-size distribution, stability, and physical properties were determined by sieve analyses, CBR tests, and Atterberg Limits tests.

Next, the original soil gradation was altered by adding aggregate according to Talbot's equation for the entire (largest to

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smallest sizes) range of sizes within the soil. The soil properties resulting from this gradation change were then tested by the CBR and Atterberg Limits tests.

Then, the effects on stability of the various sizes within the altered gradation (Talbot's gradation) were determined by omitting certain size particles from the gradation and observing the resulting change in soil properties.

Finally, different percentages of large size aggregate were added to the original soil and the resulting property changes determined by the CBR test.

Unaltered or Original Soil Testing

In order to determine why the original soil failed to meet the AASHO requirements for a base course material, tests to determine the grain-size distribution, stability, and physical properties were made.

Grain-size distribution

By use of a soil separator, four samples were prepared according to AASHO specifications. One sample was discarded. Two samples were used for grain-size analysis, one by a washed sieve analysis, the other by hydrometer analysis, both according to AASHO test (T88-57) - Standard Methods of Mechanical Analysis of Soils. Several sieve sizes (#8, #16, #30, #50, #100) were used in addition to the sizes required by AASHO test procedure. These sizes were added for subsequent use in Talbot's formula. The fourth sample was used to determine the hygroscopic moisture content.

The hydrometer analysis was modified by including a temperature correction because a constant temperature room or water bath was not available. Sodium hexametaphosphate buffered with sodium carbonate

(commercial calgon) was used as the dispersing agent for the hydrometer analysis. Dispersion of the sample was made using a mechanical stirring apparatus, stirring for one minute.

Figure 7.1 shows the results of the mechanical analysis on the native soil and gradation limits imposed by the American Association of State Highway Officials for base course material (Grading F). As shown by the figure, the natural soil did not meet AASHO (Grading F) gradation requirements. (See Table 3.1). The natural soil failed to meet the AASHO requirements because of the lack of particles larger than the No. 8 sieve coupled with an abundance of fine sizes.

Atterberg Limits

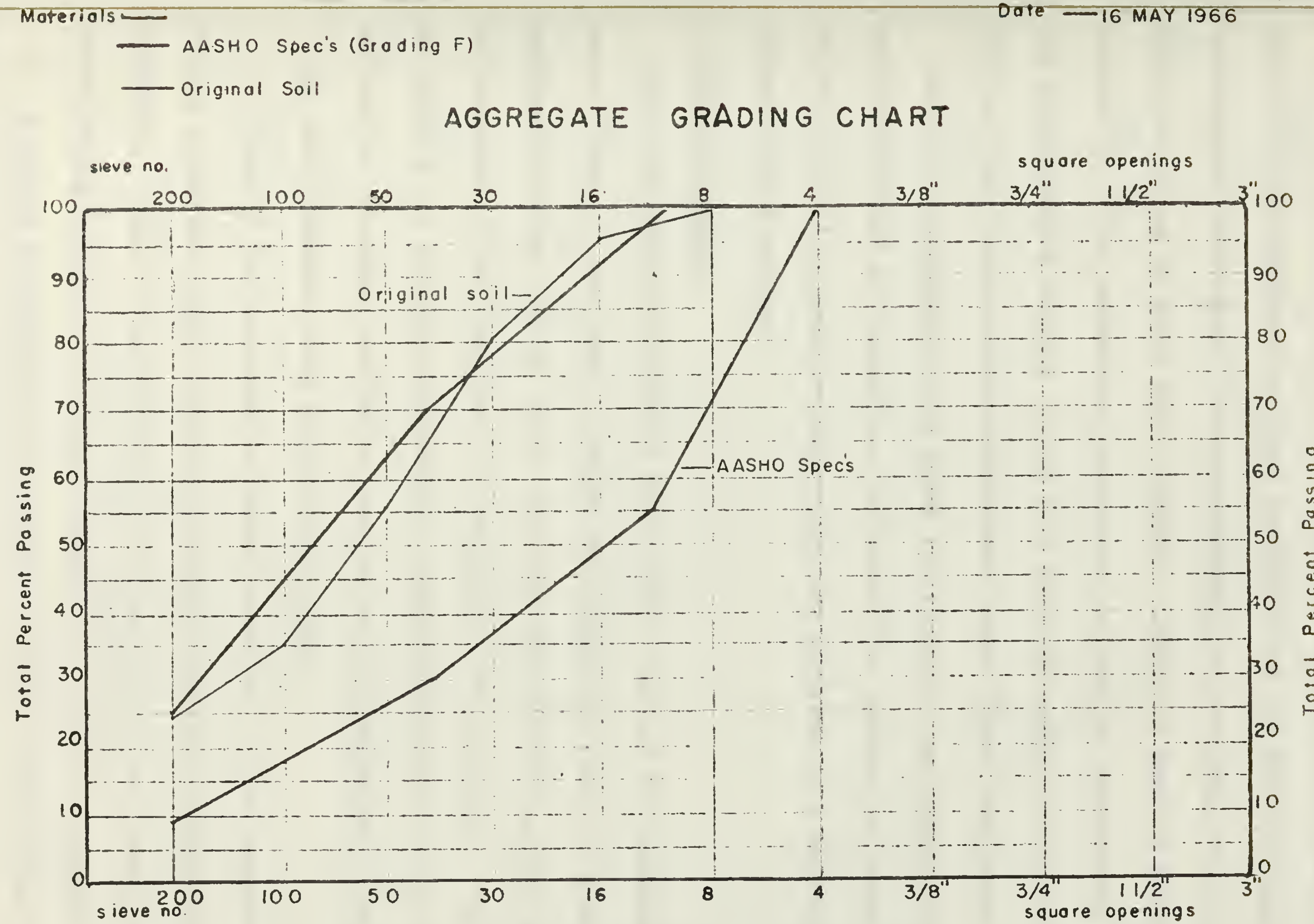
In order to classify the soil and predict soil behavior, a series of Atterberg Limits tests were made according to AASHO testing procedue (T87 thru T91). Determination of the Shrinkage Factor for the soil was not made since volumetric shrinkage due to changes in moisture content for granular soils is not critical. The results of the liquid limit and plastic limit tests are shown in Table 7.1. Results of the Atterberg Limits test proved the soil to be non-plastic (PI=0).

TABLE 7.1

ATTERBERG LIMITS

	Clay* Content (%)	Liquid Limits (%)	Plastic Limit (%)	PI%**
Original Boss Pit	6.7	18.0	19.2	0
Talbot's gradation, (conformance for all sizes)				
n=0.30	30.0	20.5	12.03	7.49
n=0.40	21.0	14.0	12.86	1.14
n=0.50	15.6	14.9	13.07	1.83
n=0.60	11.0	13.9	14.10	0.00

* Minus No. 200 size material ** Plasticity Index



ORIGINAL SOIL GRADATION

FIGURE 7.1

Moisture-density relationship

Since the supporting power of the soil increases with density (12, pg. 409), the unaltered soil was compacted and the moisture-density relationship determined. Moisture-density relationships were determined according to AASHO test (T180-57) - Moisture Density Relations (method D). This method was selected to be used in conjunction with the CBR procedure because it was felt that the values obtained from the test would more closely approximate actual field conditions.

The moisture-density curve shown in figure 7.2 was based on the moisture content at compaction. As shown, the optimum dry density of the soil was 131 pounds per cubic foot and occurred at a moisture content of 8.7 percent.

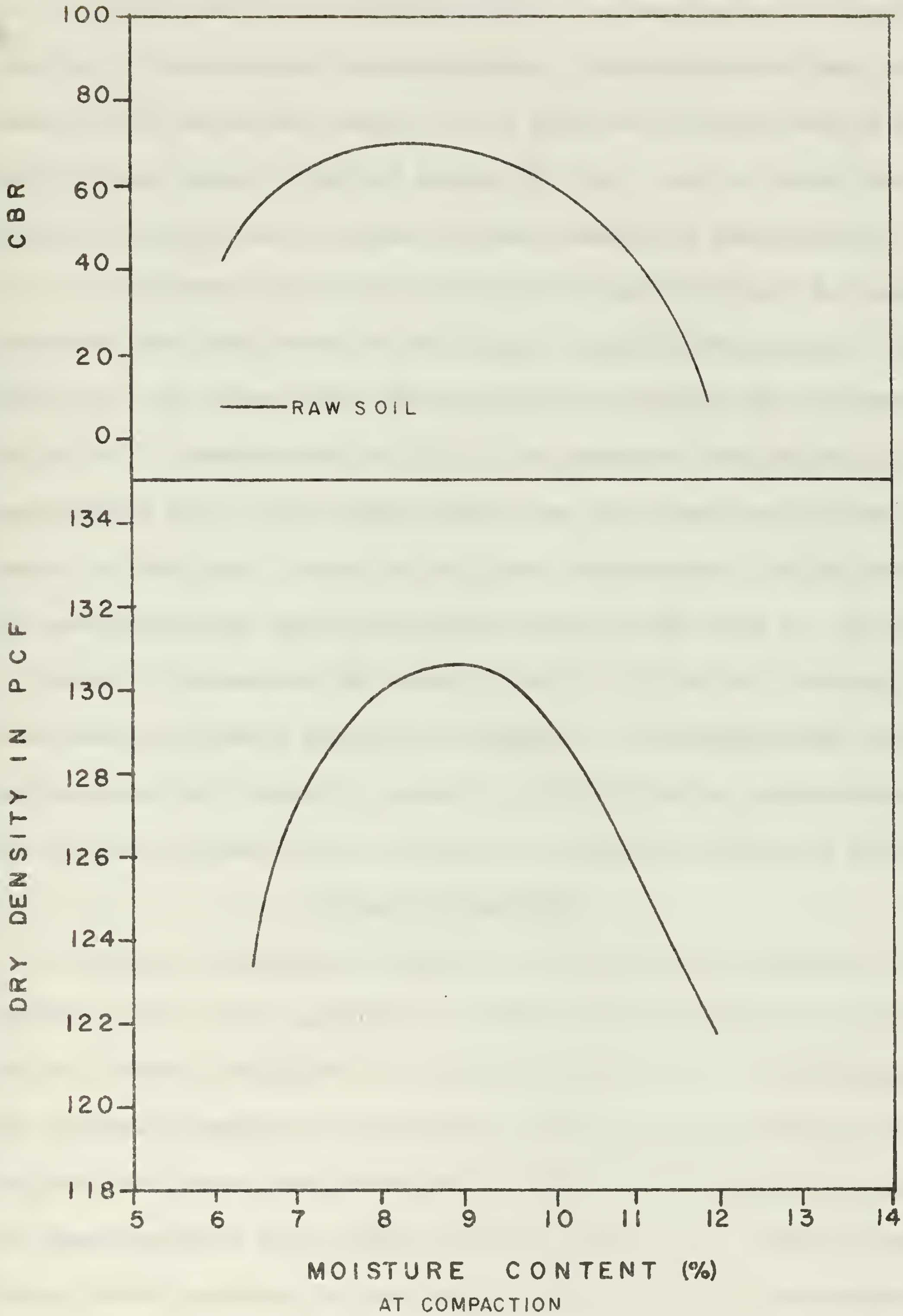
CBR test results

Since the California Bearing Ratio (CBR) test can be considered as an "Index" of the shear strength and supporting power of a soil-aggregate mixture (22, pg. 607), this test was selected as the basis for determining the stability of the granular soils tested. The American Society for Testing and Materials (ASTM) test D1883 (2, pg. 601) was used to determine the CBR values for the soil-aggregate mixtures.

The test procedure used included four parts:

1. The soil was compacted by impact according to the moisture-density procedure (AASHO T180-57) for several moisture contents close to optimum. Data for moisture-density computations were taken and the corresponding moisture and density computed for each test sample.

2. A period of soaking for four days followed, during which time swell measurements were made each day.



MOISTURE-DENSITY-CBR RELATION

FIGURE 7.2

3. At the end of the soaking period, the samples were allowed to dry for 15 minutes prior to penetration. Penetration was made at the rate of 0.05 inches per minute , to a depth of 1/2 inch, with a 2" diameter piston using a standard manual CBR rig. Load in pounds per square inch (psi) was recorded for each tenth inch penetration.

4. Load-Penetration curves were plotted and corrected for upward concavity and sharp bends at the origin resulting from surface irregularities. CBR values were then obtained by dividing the corrected load in psi at .1" penetration by 10 and the corrected load in psi at .2" penetration by 15. The larger of the two values was used as the CBR value for the test. Since the soil was a silty-sand, the CBR value at .2" penetration was generally larger than the CBR value at .1" penetration.

Figure 7.2 shows the CBR values obtained for the soil plotted as functions of moisture content at compaction. The maximum CBR was 70.5 and occurred at a moisture content of 8.5%, while the maximum density of 131 lbs. per cubic foot occurred at a moisture content of 8.7%.

Talbot's Gradations

In order to increase the stability and improve the physical properties of the soil, aggregate was mixed with the original soil to satisfy Talbot's equation for various values of 'n'. The effects of the gradation changes on the physical properties and stability of the original soil were then determined by CBR and Atterberg Limits tests. By comparing these test results for each value of 'n' tested, the optimum Talbot gradation for the range of sizes added was determined.

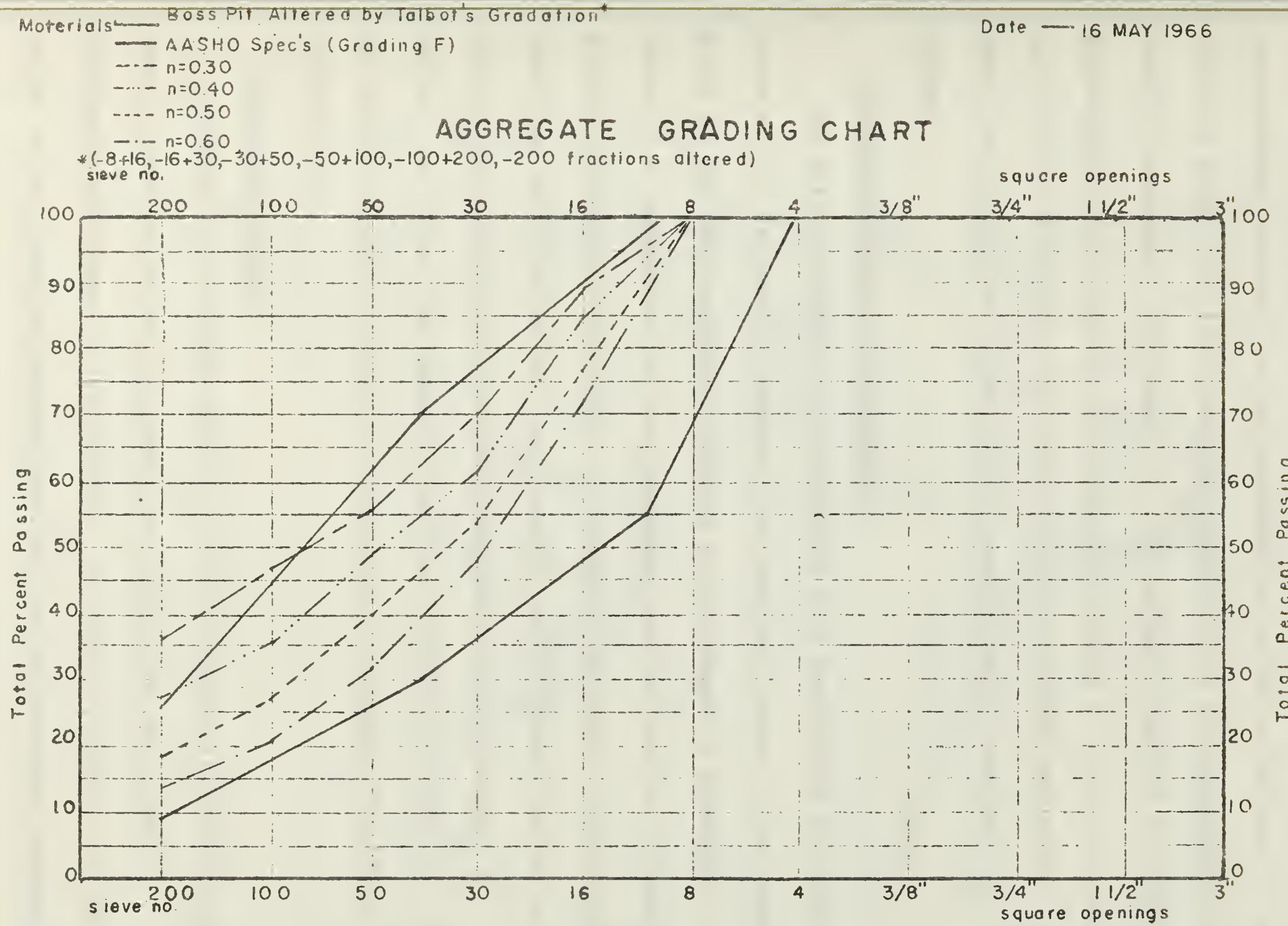
It is to be noted that Talbot's gradations, as used in this paper, refers only to those soil-aggregate mixtures whose grain-size

distributions were changed to satisfy Talbot's equation for various values of 'n' by adding aggregate for the entire range of particle sizes contained in the soil (#8, #16, #30, #50, #100, #200 sizes).

Grain-size distribution

The range of particle sizes added to satisfy Talbot's equation for each value of 'n' included particles retained on each standard sieve size from the No. 8 size sieve to the No. 200 size sieve (#8, #16, #30, #50, #100, #200 sizes). These sizes were the same as those used in the mechanical analysis of the natural soil. Material passing the No. 200 size sieve was added also. The amount of particles to be added for each size considered was then determined by Talbot's formula. Aggregate which had been previously separated by the standard sieve sizes considered was then added to the original soil so that the resulting gradation contained the amount of each particle size as computed by Talbot's equation. The minus No. 200 size material was added in the form of a clay slurry. A washed sieve analysis was made after testing to check to see that the grain-size distributions used were the same as those computed.

The results of the grain-size distributions for various values of 'n' are shown in figure 7.3. The curves were determined by plotting the percentage by weight of material passing a given sieve size. As shown, most of the gradations met the AASHO grading F base course requirements. For values of 'n' equal to 0.5 and 0.6, the gradations fell well within AASHO's required gradation limits. However, the soil-aggregate mixtures still lacked large size particles required by AASHO specifications for better base course materials.



TALBOT'S GRADATIONS

FIGURE 7.3

Atterberg limits

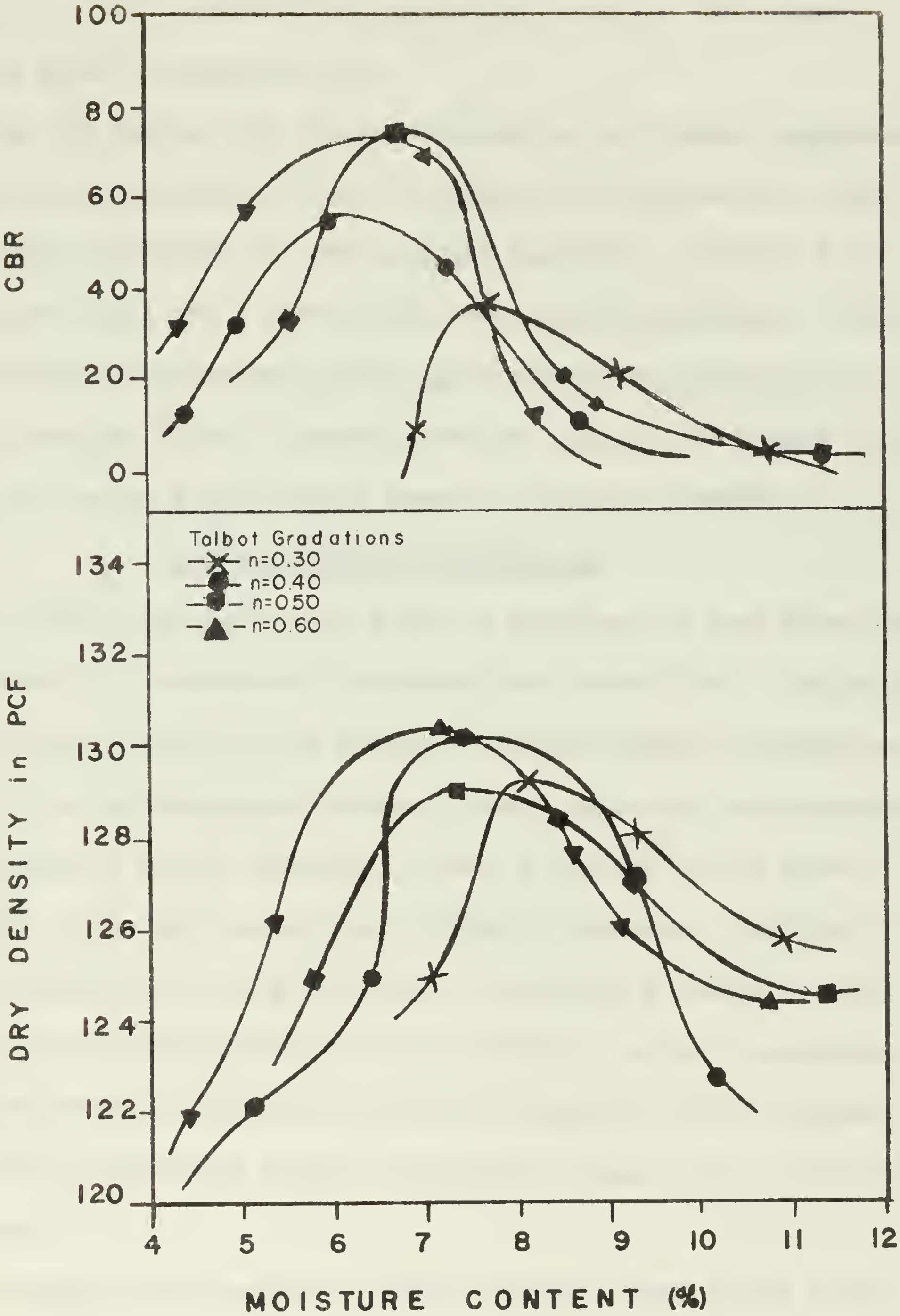
In order to satisfy Talbot's gradation for the entire range of sizes within the soil, a clay material was added to the soil. As shown in table 7.1, the plasticity index of the soil-aggregate mixture greatly increased. The amount of clay content required by Talbot's gradation equation varied inversely with values of 'n', i.e., as the value of 'n' increased, the amount of clay required decreased. As shown, the plasticity index varied proportionally with the clay content.

Moisture-density relationships

The moisture-density relationships were determined for each value of 'n' in order to examine the possible change in the supporting power of the soil-aggregate mixtures with changes in gradation. In figure 7.4, densities for each gradation were plotted as a function of moisture content at compaction. Figure 7.4 indicates that the maximum densities obtained did not vary greatly with different values of 'n', but the optimum moisture content decreased with increasing 'n' values. As shown, the maximum densities obtained for each 'n' value in Talbot's equation were not as great as the maximum density of the natural soil.

CBR test results

Although the maximum density of the altered soil did not vary greatly with variations in gradation, CBR values were greatly influenced by changes in gradations. As shown in figure 7.4, the values of CBR obtained depended not only on the moisture content at the time of compaction, but also on the gradation of the soil-aggregate mixtures. The maximum CBR values obtained for each gradation in



MOISTURE-DENSITY-CBR RELATION

FIGURE 7.4

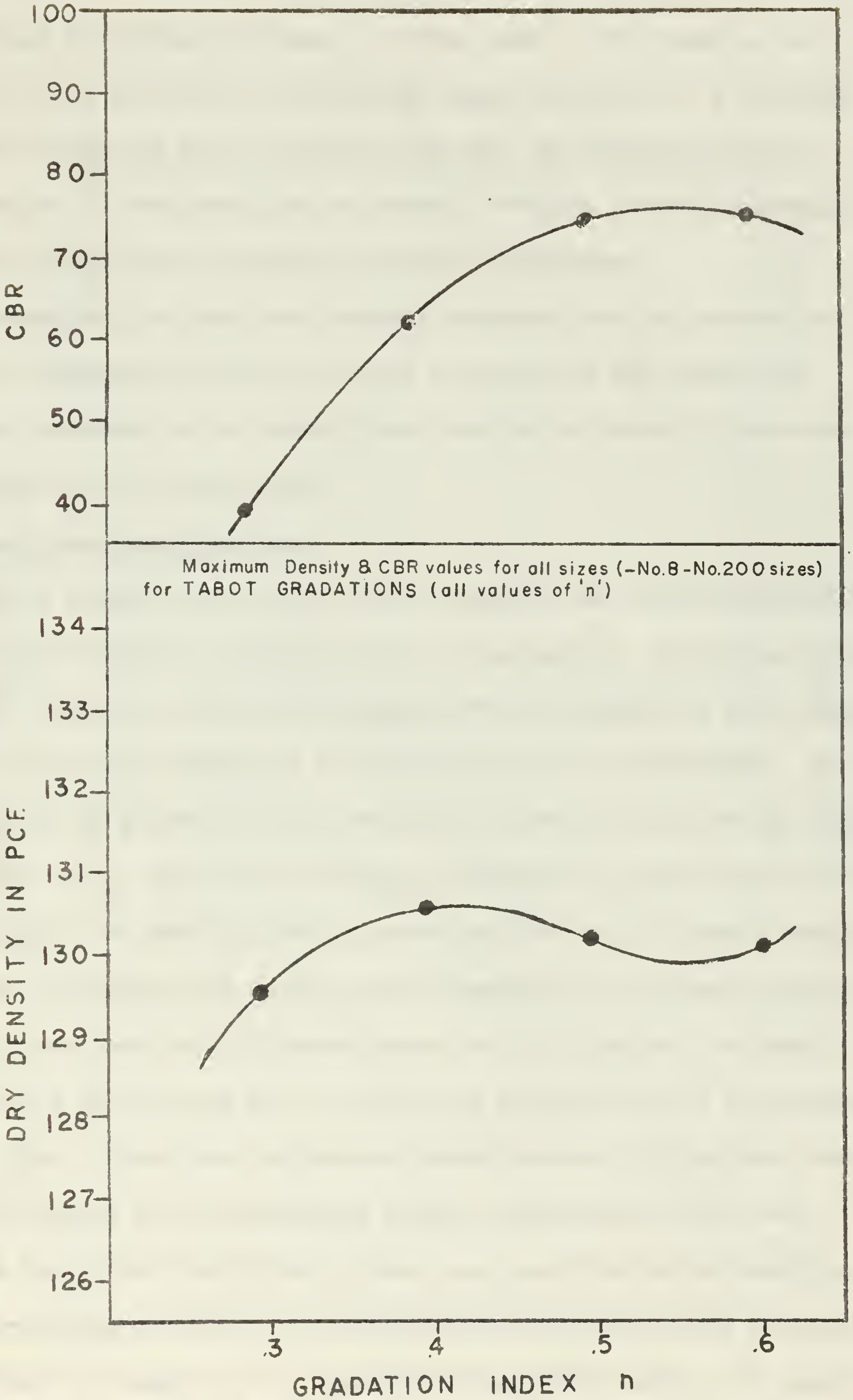
figure 7.4 were plotted as a function of the gradation index (n) in figure 7.5. The optimum Talbot gradation, based on CBR values, occurred when 'n' equaled 0.50.

When the maximum CBR values obtained for all Talbot gradations considered were compared with the original soil maximum CBR value, only a slight increase in stability had occurred, (a CBR=70.5 for the original soil and a CBR=73.0 for the altered gradation). Therefore, the addition of approximately 50% aggregate to the natural soil in order to satisfy Talbot's equation did not upgrade the natural soil enough for use as a base course material (required CBR=80).

Modified Talbot's Gradations

In order to determine why Talbot's equation, as used above, was unsuccessful in substantially upgrading the natural soil, the equation was modified slightly by the author. Modified Talbot's gradations refer to the soil-aggregate mixtures whose grain-size distributions were altered by adding aggregate to only a portion of the sizes contained in the soil according to Talbot's equation. Modified Talbot's gradation is then different from Talbot's gradation only with respect to the portion of sizes altered. Talbot's gradations alter the amount of all particle sizes considered in the original soil while the Modified Talbot's gradations change only a portion of the sizes.

According to the modified Talbot procedure used in the paper many different gradations resulted because of the different values of 'n' considered and the number of different portions which could be altered. Each gradation was identified by stating the value of 'n' used in Talbot's equation to determine the amount of the various sizes



GRADATION-DENSITY-CBR RELATION

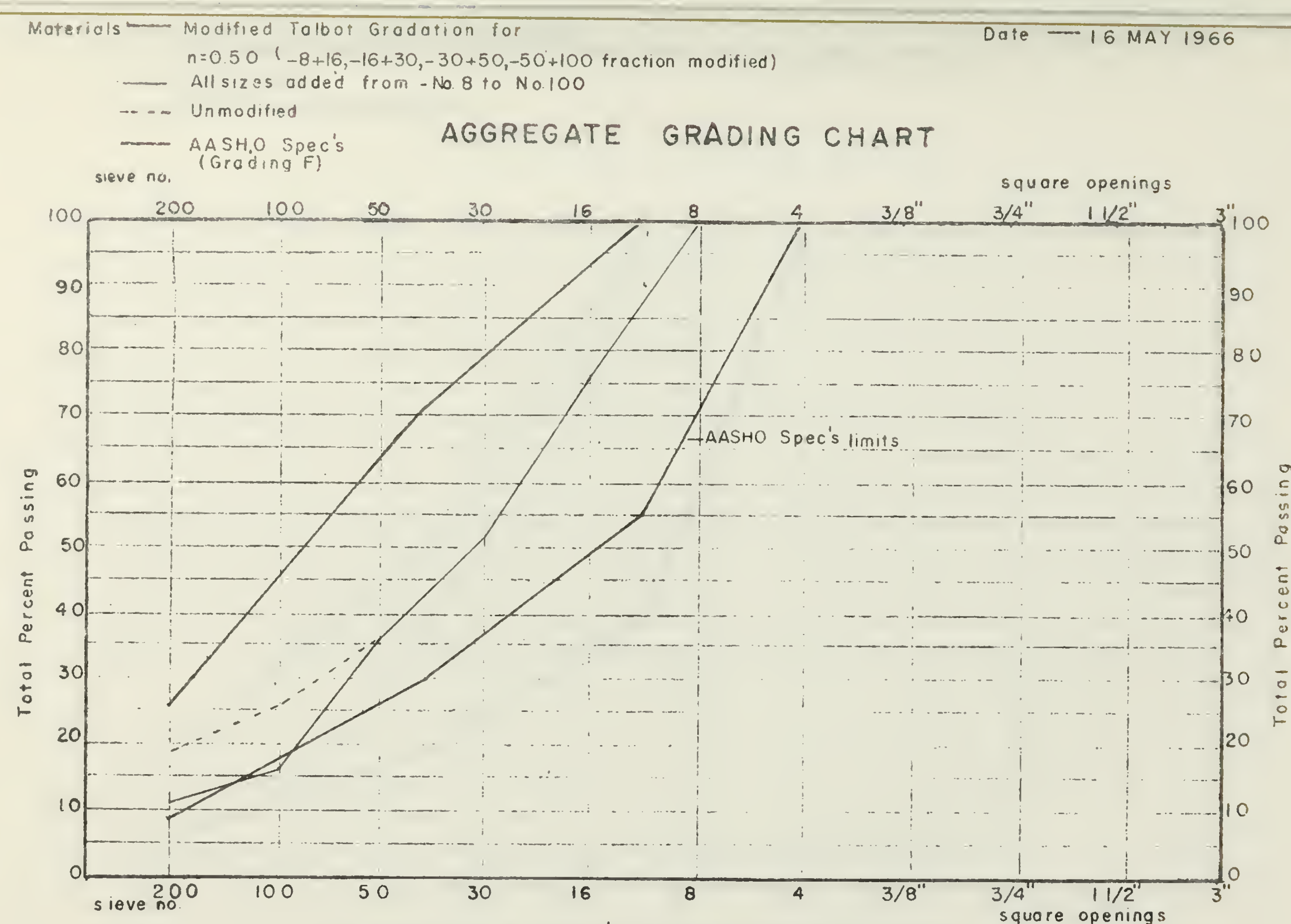
FIGURE 7.5

to add and by stating the range of sizes added. For example, in figure 7.6a a grain-size distribution curve is shown for a Modified Talbot's gradation for 'n' equals 0.50 with the portion of sizes from the No. 8 size particles to the No. 100 size particles changed in the original soil according to Talbot's equation.

Therefore, the Modified Talbot's gradation are the same as the Talbot's gradations except that only a portion of the sizes were changed according to the formula vice the entire range of particles contained in the original soil.

Grain-size distributions

Since Talbot's gradations did not upgrade the soil significantly, the Modified Talbot's gradations were investigated. According to the Modified Talbot procedure for changing the soil gradation there would be four different gradations for each value of 'n' considered. The four resulting grain-size distributions for n=0.50 are shown in figures 7.6a thru 7.6d. Only four gradations resulted for each value of 'n' according to the Modified Talbot procedure used in this paper because only the following four portions were changed by the formula; minus No. 8 to the plus No. 100 sizes, minus No. 8 to plus No. 50 sizes, minus No. 8 to the plus No. 30 sizes, and the minus No. 8 to the plus No. 16 size. Since each succeeding sample omitted the smallest size particles added to the preceeding sample, comparison of the test results would show the effect of each size particle on the stability of soil-aggregate mixture. To insure that the test results were not influenced by changes in the quantity of aggregate added, the weight of aggregate added was maintained constant for each value of 'n'. A constant weight for each value of 'n' was maintained by including the



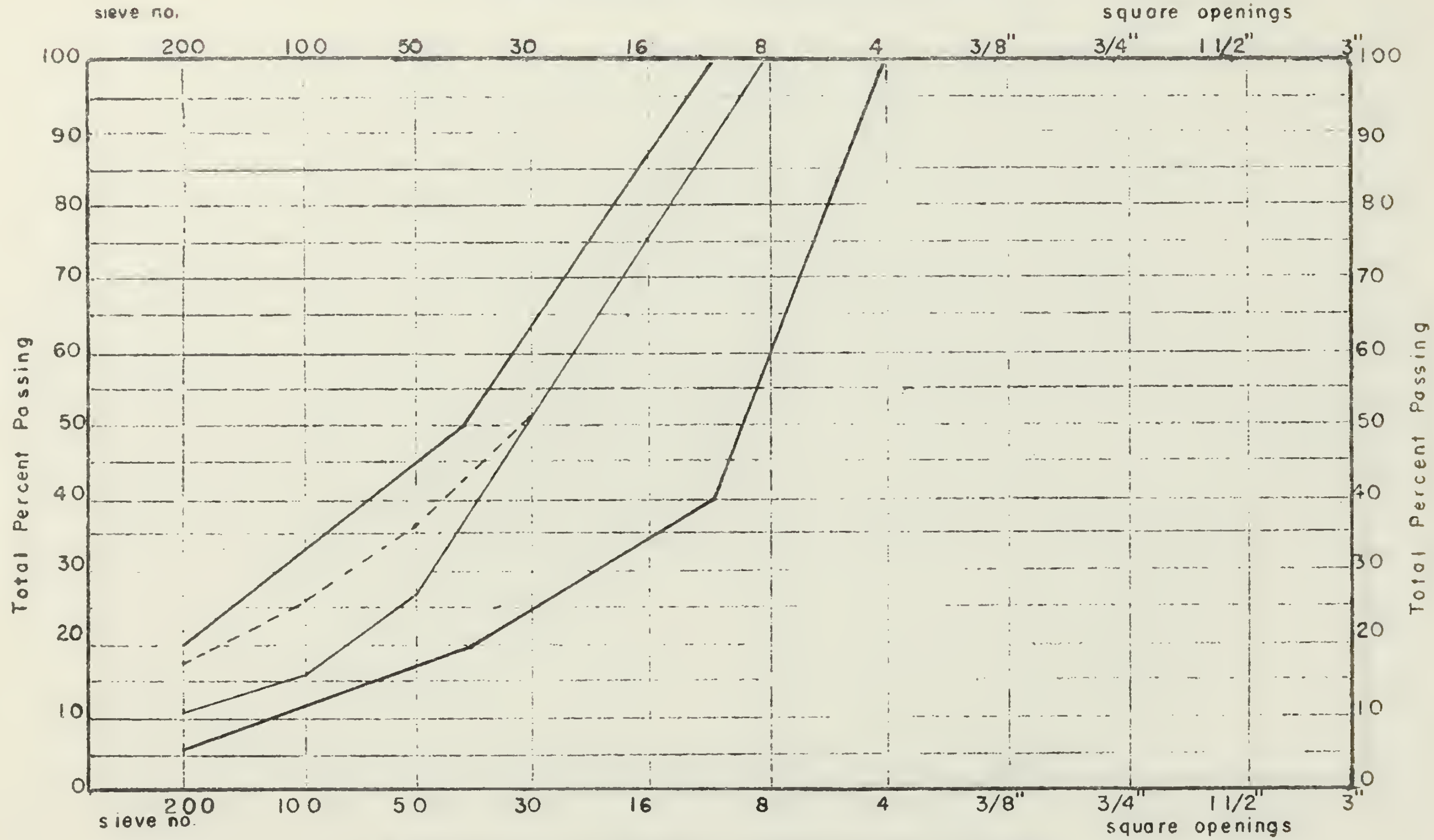
MODIFIED TALBOT'S GRADATION (n=0.50)

FIGURE 7.6A

Materials —— Modified Talbot Gradation for n=0.50
—— Sizes added from - No. 8 to No. 50 . (-8+16,-16+30,-30+50 fraction modified)
- - - Unmodified
—— AASHO Spec's (Grading E)

Date —— 16 MAY 1966

AGGREGATE GRADING CHART



MODIFIED TALBOT'S GRADATION (n=0.50)

FIGURE 7.6B

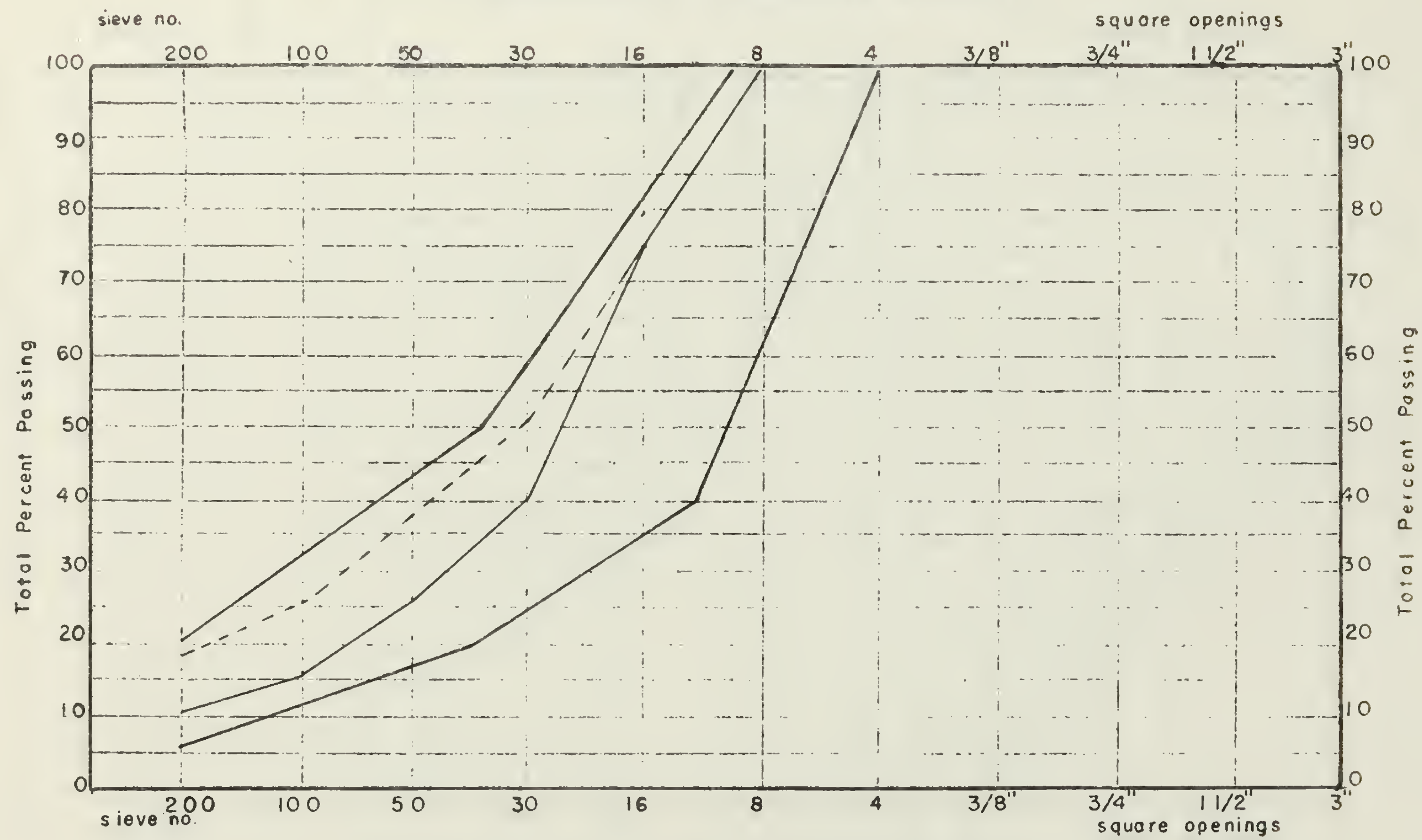
Materials —— Modified Talbot Gradation for n=0.50 Date —— 1966

—— Sizes added from -No.8 to No 30 (-8+16,-16+30 fractions modified)

-.--- Unmodified

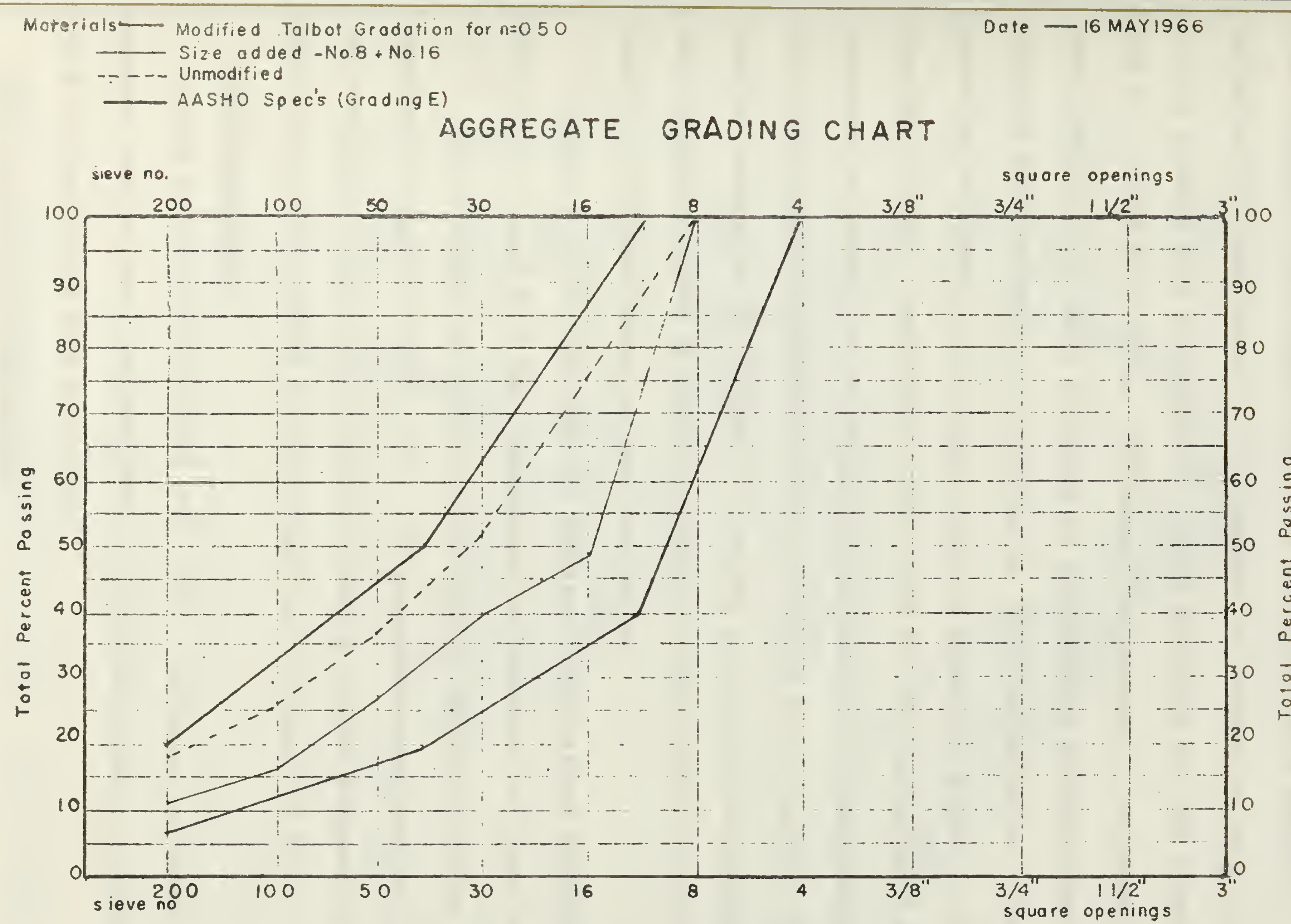
—— AASHO Spec's (Grading E)

AGGREGATE GRADING CHART



MODIFIED TALBOT'S GRADATION (n=0.50)

FIGURE 7.6c



MODIFIED TALBOT'S GRADATION (n=0.50)

FIGURE 7.6D

weight of the omitted size particles with the smallest size added to that portion. For example, the first modification of Talbot's gradation (for any value of 'n') changed the portion of sizes altered by the formula from the minus No. 8 thru the minus No. 200 sizes to the No. 8 thru the plus No. 100 sizes. The weight of the minus No. 100 size particles not added according to the modified procedure was included with the weight of the plus No. 100 size particles. The next modification added particle sizes from the minus No. 8 size to the plus No. 50 size. The weight of the minus No. 50 size material not added was included with the weight of the plus No. 50 size particles. This process was continued until only the minus No. 8 plus No. 16 size portion remained to be changed. According to the modified procedure used the weight added of this one size would then equal the sum of the weights of all the remaining sizes not added.

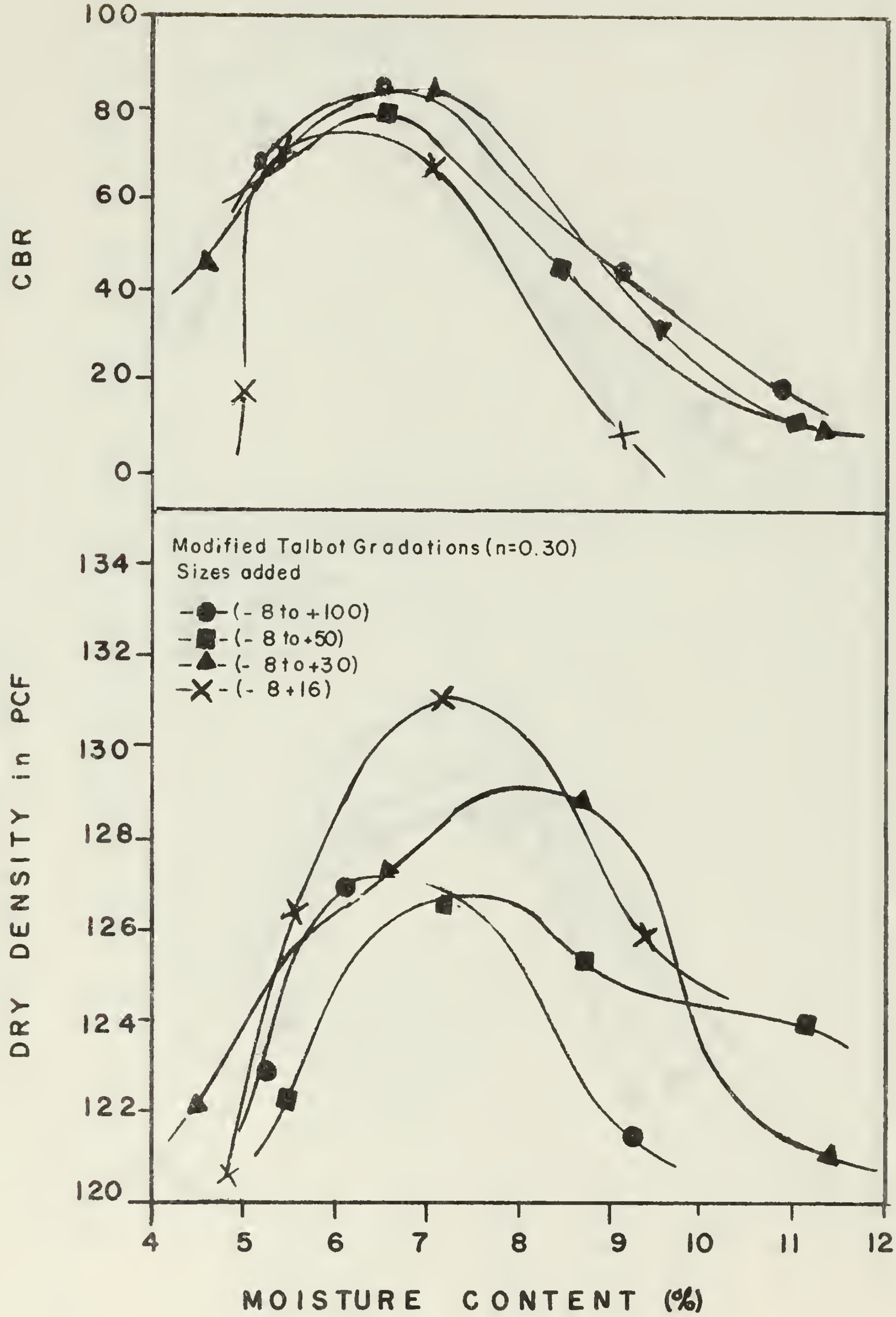
Figures 7.6a to 7.6d show the results of the various modifications made for 'n' equal to 0.50. Grain-size distributions for other values of 'n' are not shown, but the moisture-density-CBR relationships are recorded in figures 7.7a to 7.7d. The grain-size distributions for the remaining values of 'n' considered were not shown because of the similarity of curve shape to those shown for 'n' equal to 0.50.

<u>Atterberg limits</u>

Since the original soil was non-plastic and since the binder material was not added, as required by the modified Talbot procedure, the Atterberg limits were not tested.

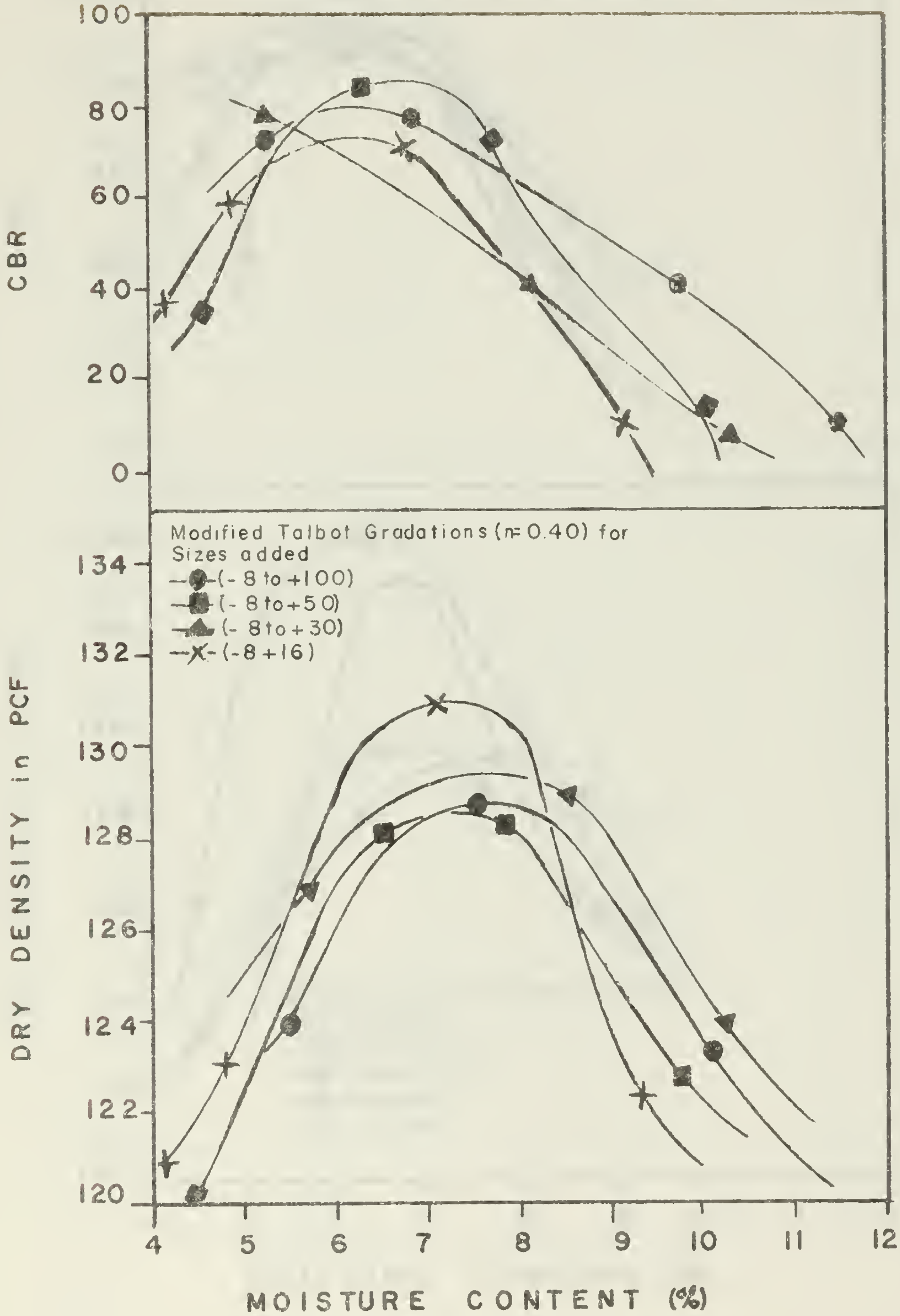
<u>Moisture-density relationships</u>

Moisture-density relationships were determined after compaction for each modification made for the different values of 'n'. The



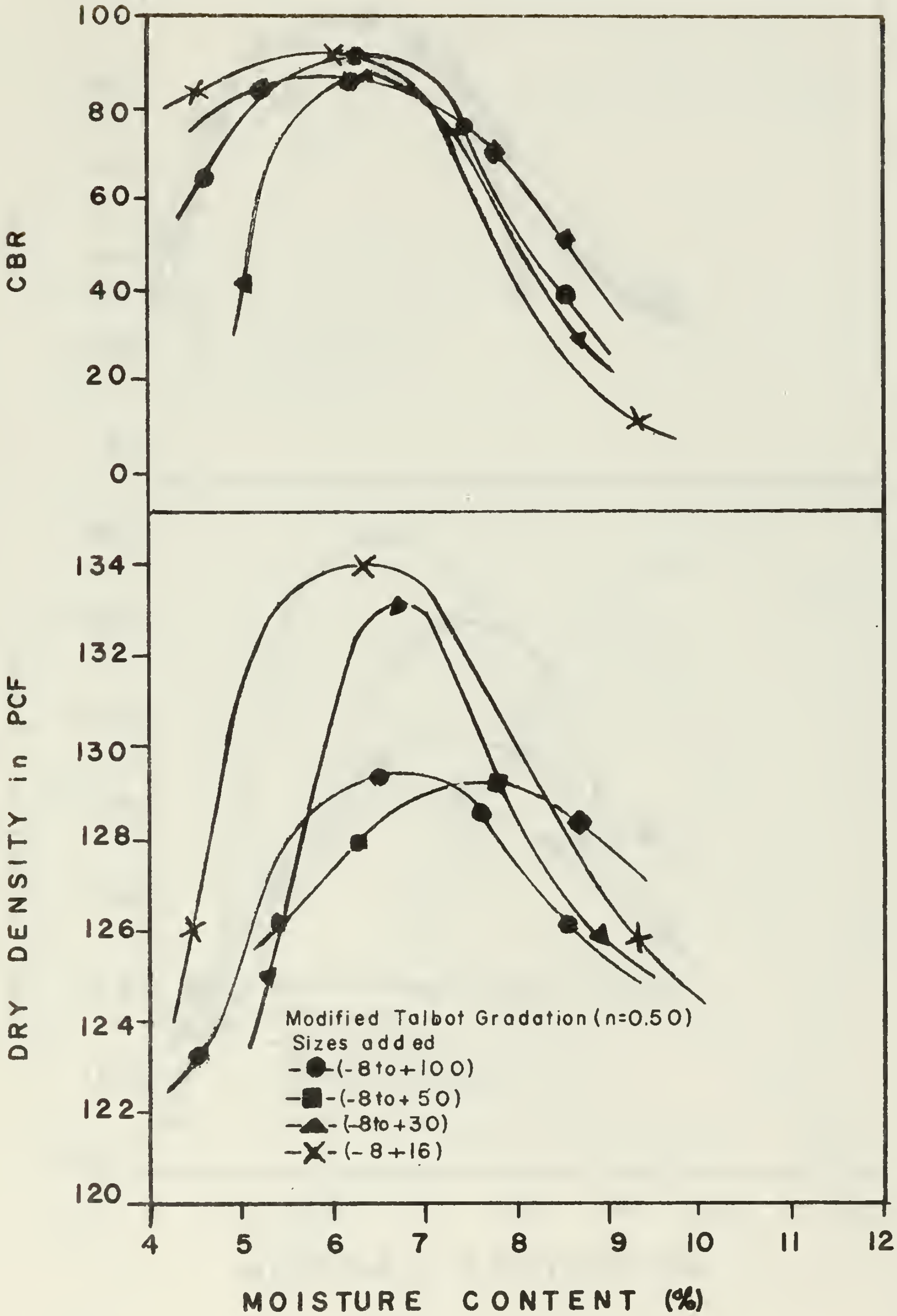
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.7A



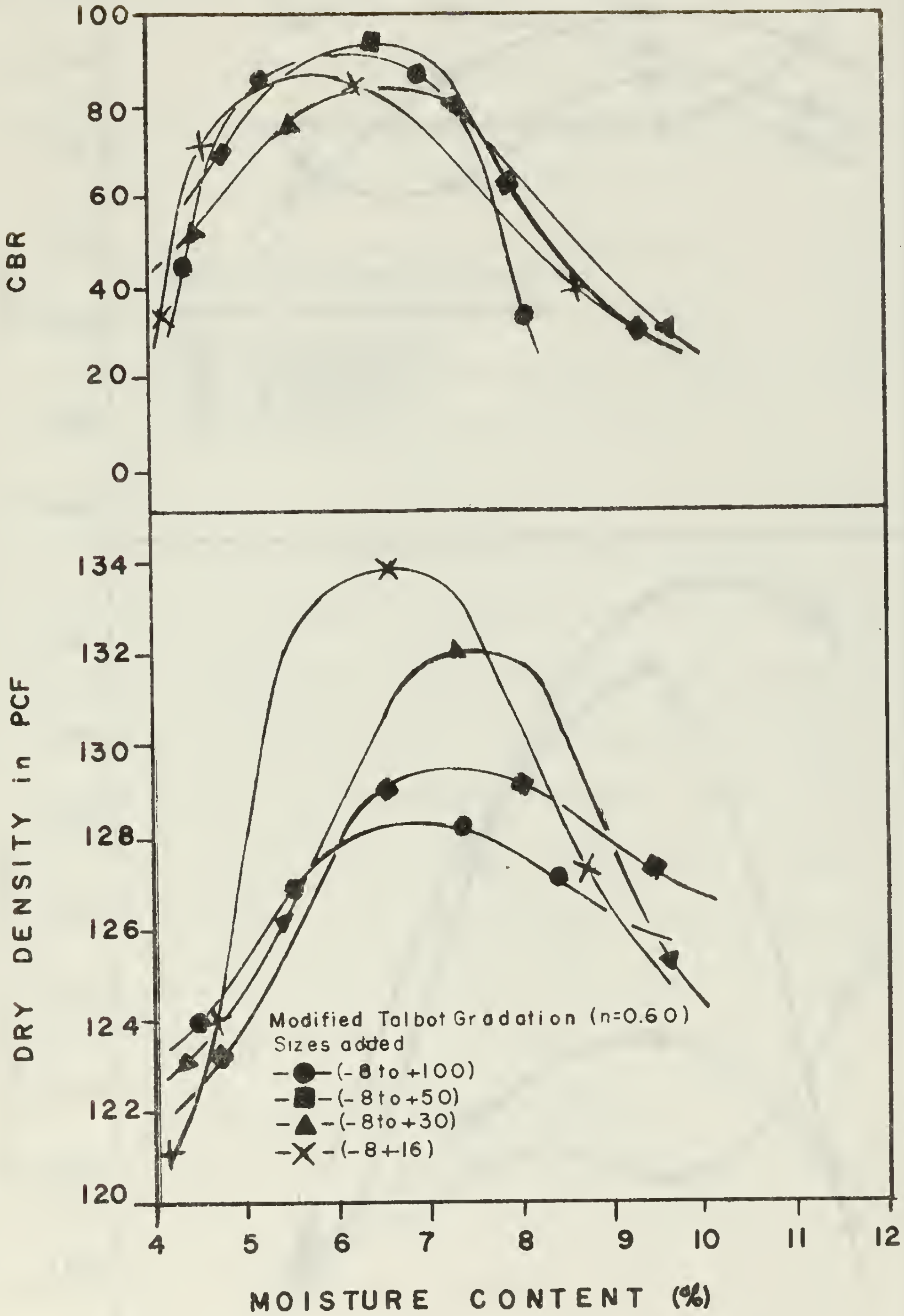
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.7B



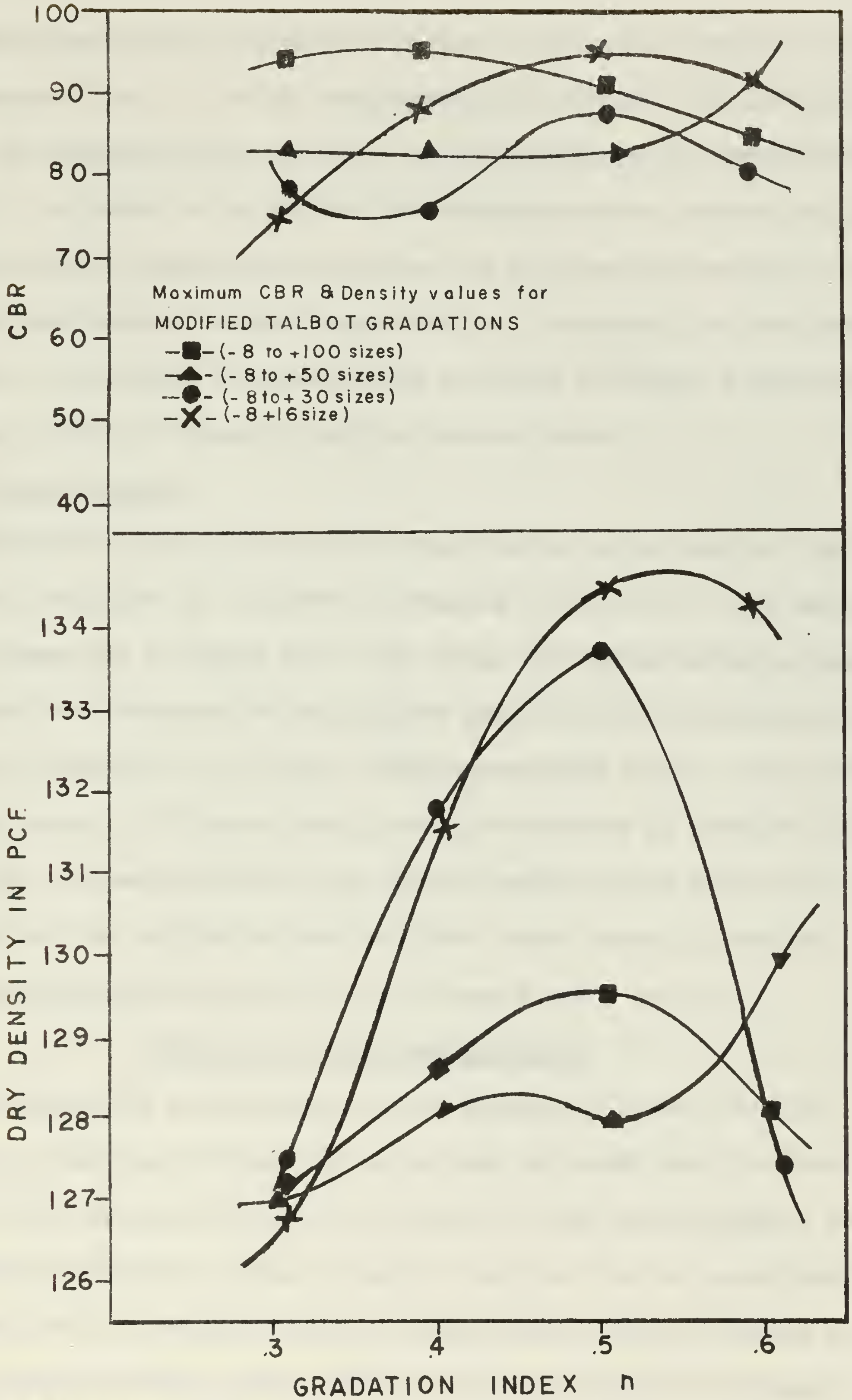
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.7c



MOISTURE-DENSITY-CBR RELATION

FIGURE 7.7D



GRADATION-DENSITY-CBR RELATION

FIGURE 7.8

moisture-density data collected for each modification made are plotted in figures 7.7a to 7.7d and then summarized in figure 7.3, by plotting only the maximum density obtained for each gradation for various values of 'n'. As shown in the figures the optimum moisture content and CBR values did not change greatly between the different gradations, but the maximum density changed significantly. Therefore, for this granular soil, the larger particles added according to Talbot's equation had more effect on density than the smaller sizes.

CBR test results

The results of the CBR tests for each modification made for the various values of 'n' are shown in figures 7.7a to 7.7d. The data was then summarized in figure 7.8. CBR values and corresponding moisture contents were obtained for each Talbot modification for different 'n' values (figures 7.7a to 7.7d). These maximum CBR values corresponding to each value of 'n' were then plotted as functions of moisture content. As shown, the maximum CBR values for all modifications were high enough for the soil to be used as a base course material when the moisture content at compaction was between 6 and 8 percent.

Addition of Large Size Aggregate

The grain-size distributions of the original soil and those of Talbot's gradations studied failed to meet the AASHO specifications for base course material because of the lack of large size aggregate and of too low CBR values. Even though the modified Talbot gradations did upgrade the soil enough for use as a base course material (based on AASHO specifications), these gradations were not desirable because of the large amount of material required to produce them. Since the

economic worth of any granular stabilization method depends on the amount or percent of material that must be added to achieve stabilization, the effects of adding 10, 20 and 30 percent of larger aggregate were checked for density and CBR values.

<u>Grain-size distribution</u>

The natural soil gradation was altered by adding 10, 20 and 30 percent of large size aggregate. One size was added per sample for each of the sizes retained on the standard sieve sizes from the minus No. 8 plus No. 16 sizes to the minus 1/2" plus 3/8" sizes (-8+16, -4+8, -3/8+4, -1/2"+3/8") for each percent. A combination of two of these sizes minus 3/8" plus No. 4 and minus No. 4 plus No. 8, was tested using 5, 10 and 15 percent of each size with succeeding samples. The combination was tested in order to determine which was the most important, the size or the amount of the aggregate added.

As shown in figures 7.9a to 7.9d, the addition of large size aggregate to the natural soil produced gradations acceptable as base course material by AASHO specifications.

<u>Atterberg limits</u>

Since all the aggregate sizes added to the original non-plastic soil were greater than the No. 40 size sieve, the Atterberg limits were not tested. (Only material below the #40 size sieve is tested for plasticity by AASHO specifications, Test T87, (1, pg. 284).

<u>Moisture-density results</u>

The moisture-density relationship for each altered sample was determined after compaction. Figure 7.10 shows a plot of moisture-density values obtained for each size for the different percentages

Materials —— Original Soil with Date —— 16 MAY 1966

−8 +16 size aggregate added for

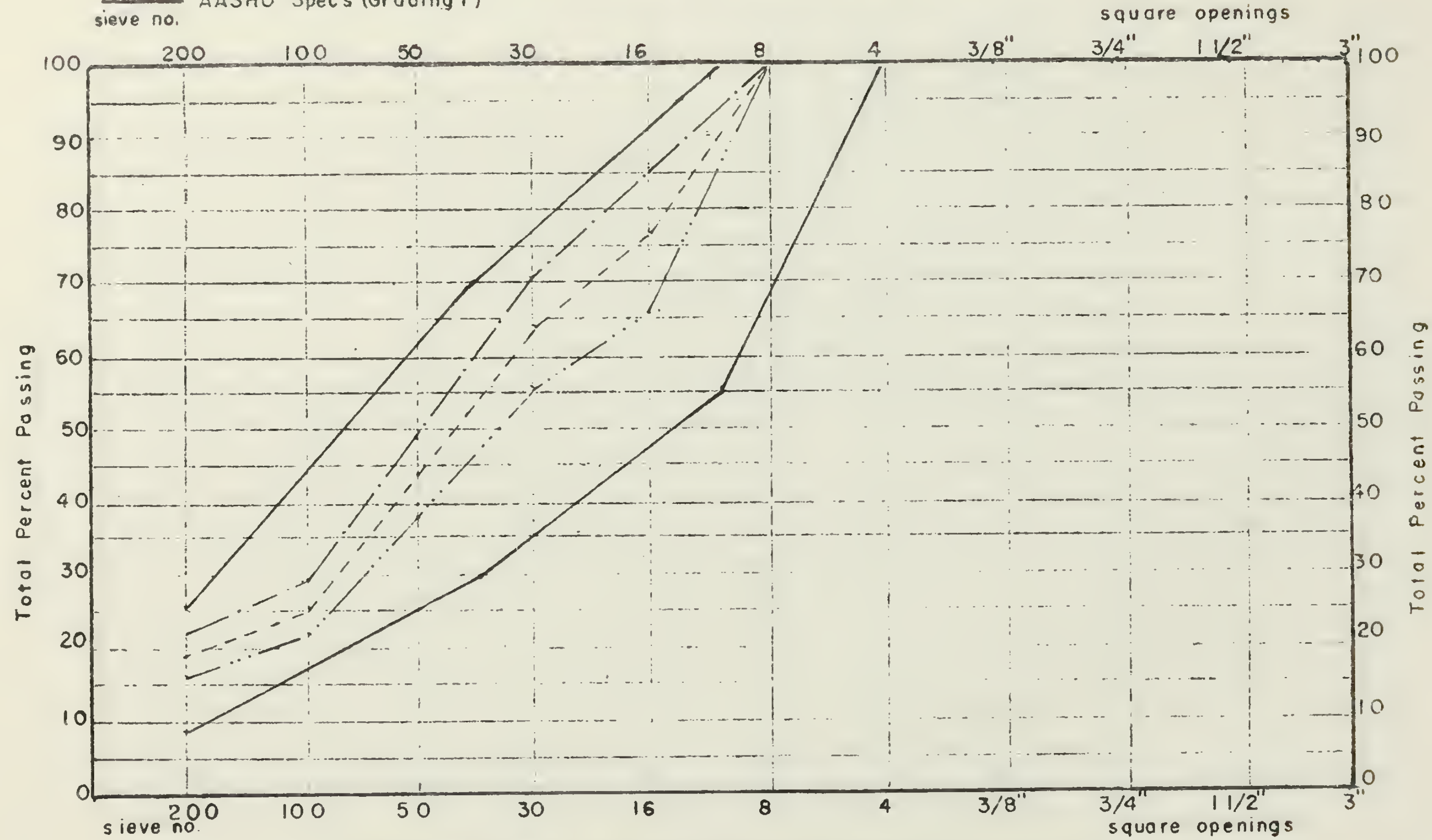
—·— 10 %

- - - - 20%

—··— 30%

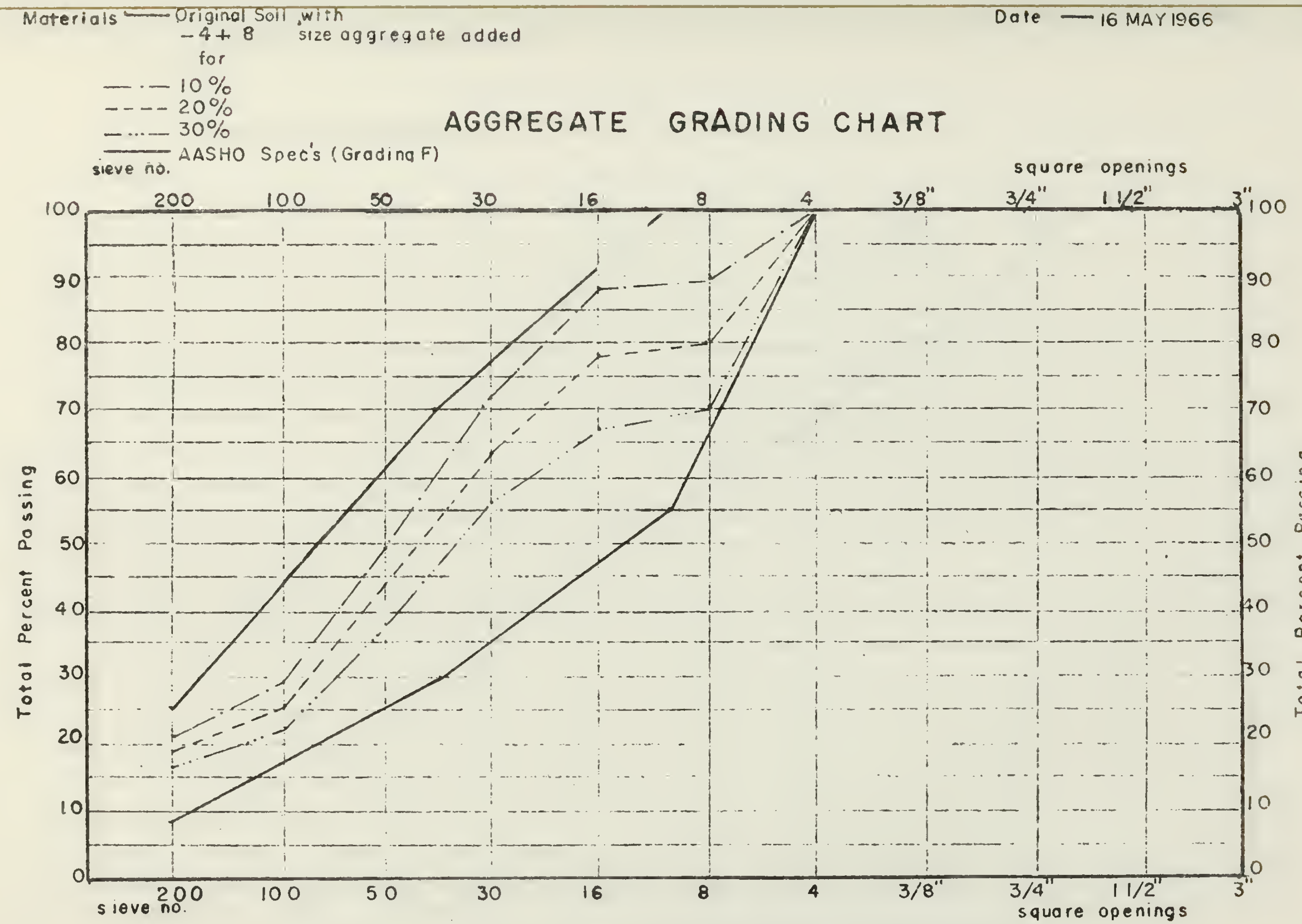
——— AASHO Spec's (Grading F)

AGGREGATE GRADING CHART



ORIGINAL SOIL WITH LARGE AGGREGATE ADDED

FIGURE 7.9A



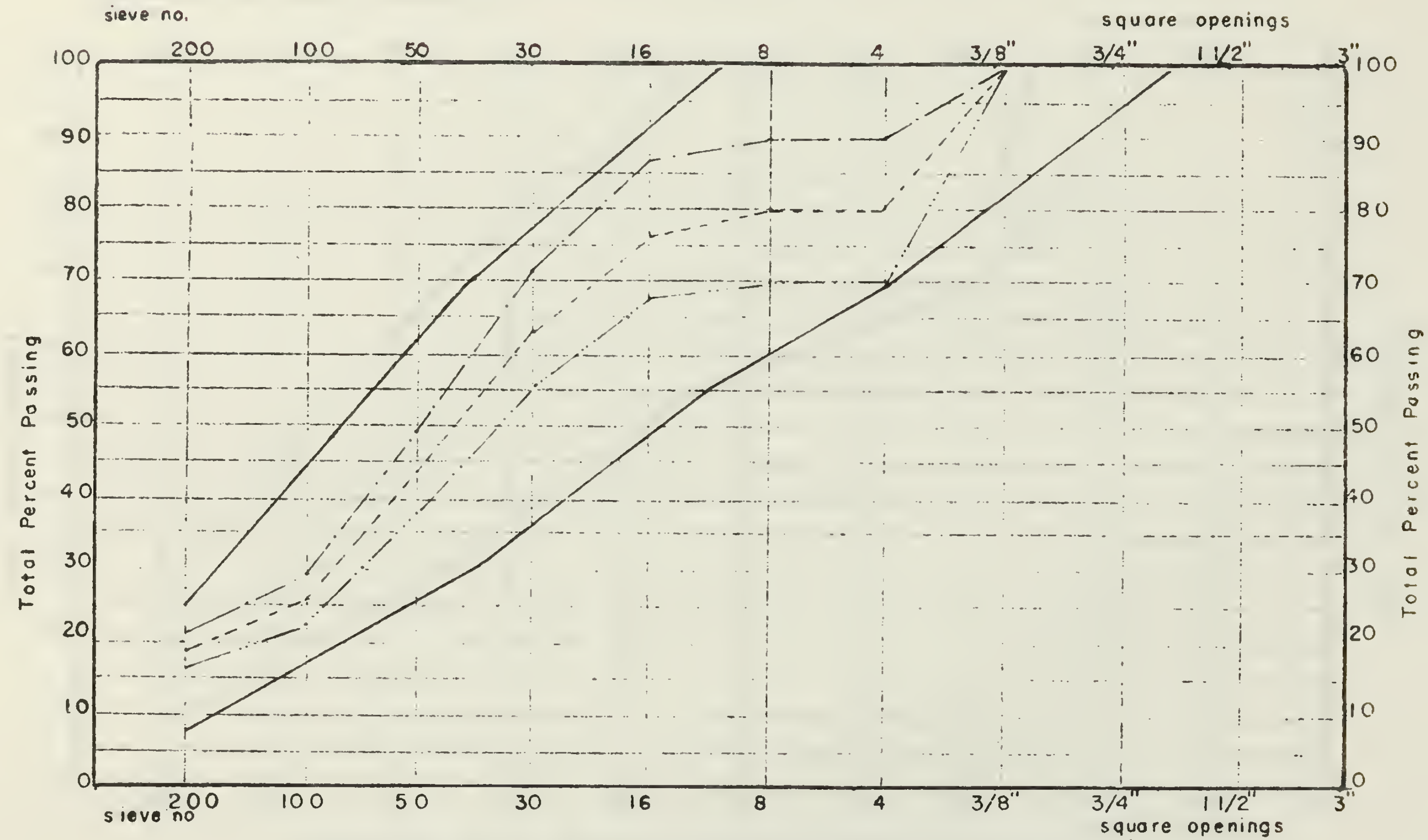
ORIGINAL SOIL WITH LARGE AGGREGATE ADDED

FIGURE 7.9B

Materials —— Original Soil
−3/8" + 4 size aggregate added
—·— 10 %
– – – – 20 %
—···— 30 %
——— AASHO Spec's. (Grading F)

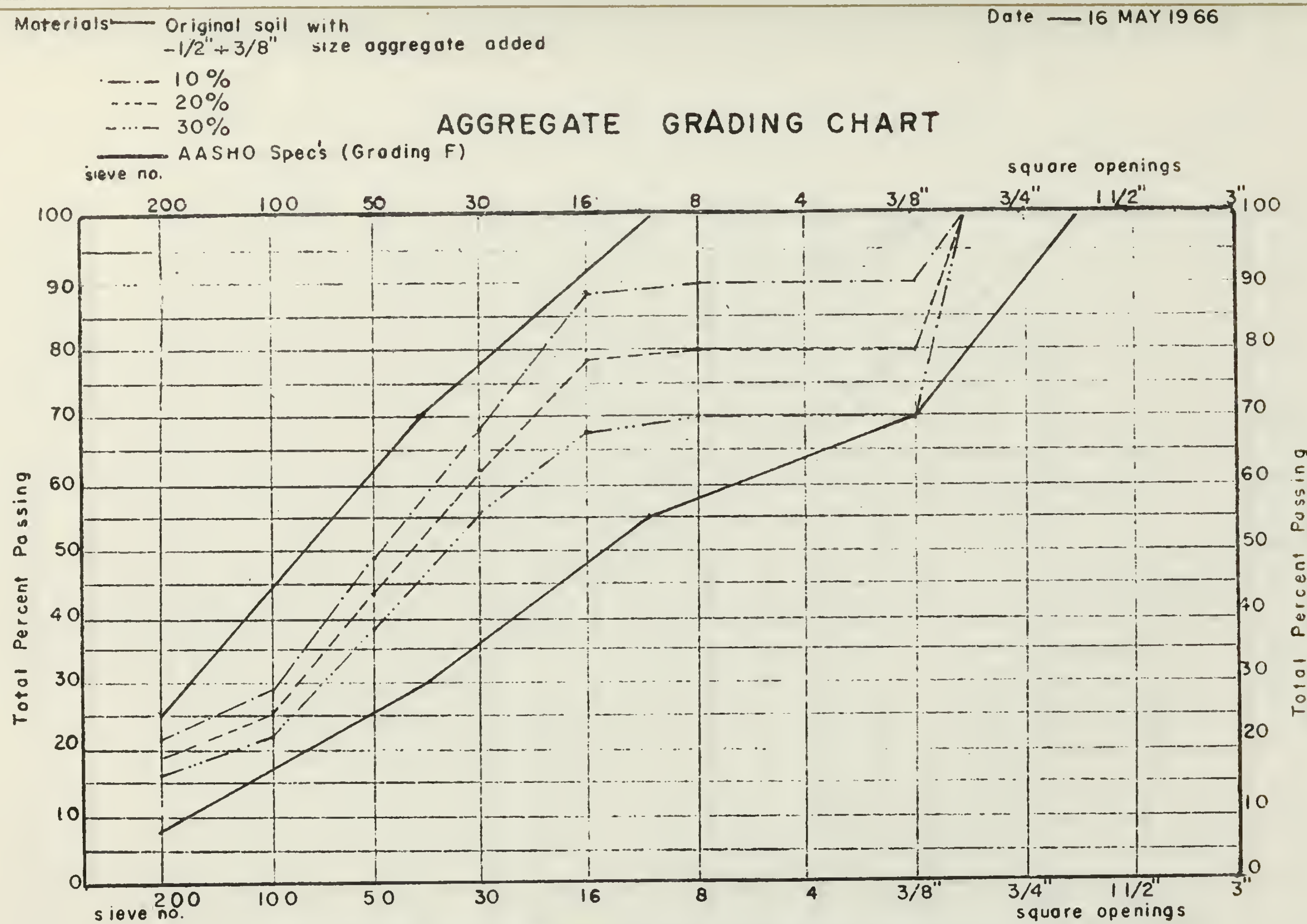
Date —— 16 MAY 1966

AGGREGATE GRADING CHART



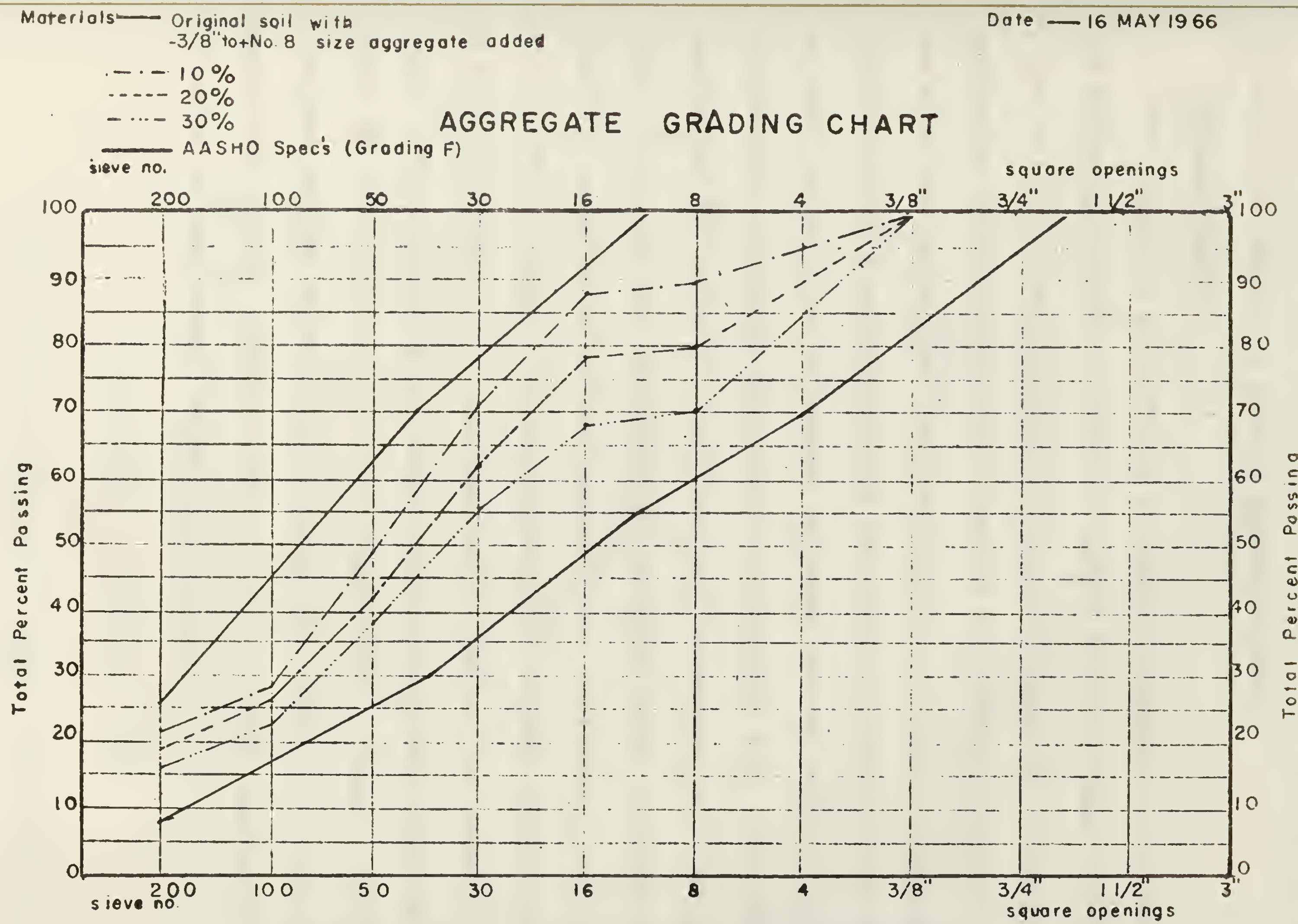
ORIGINAL SOIL WITH LARGE AGGREGATE ADDED

FIGURE 7.9c



ORIGINAL SOIL WITH LARGE AGGREGATE ADDED

FIGURE 7.9D



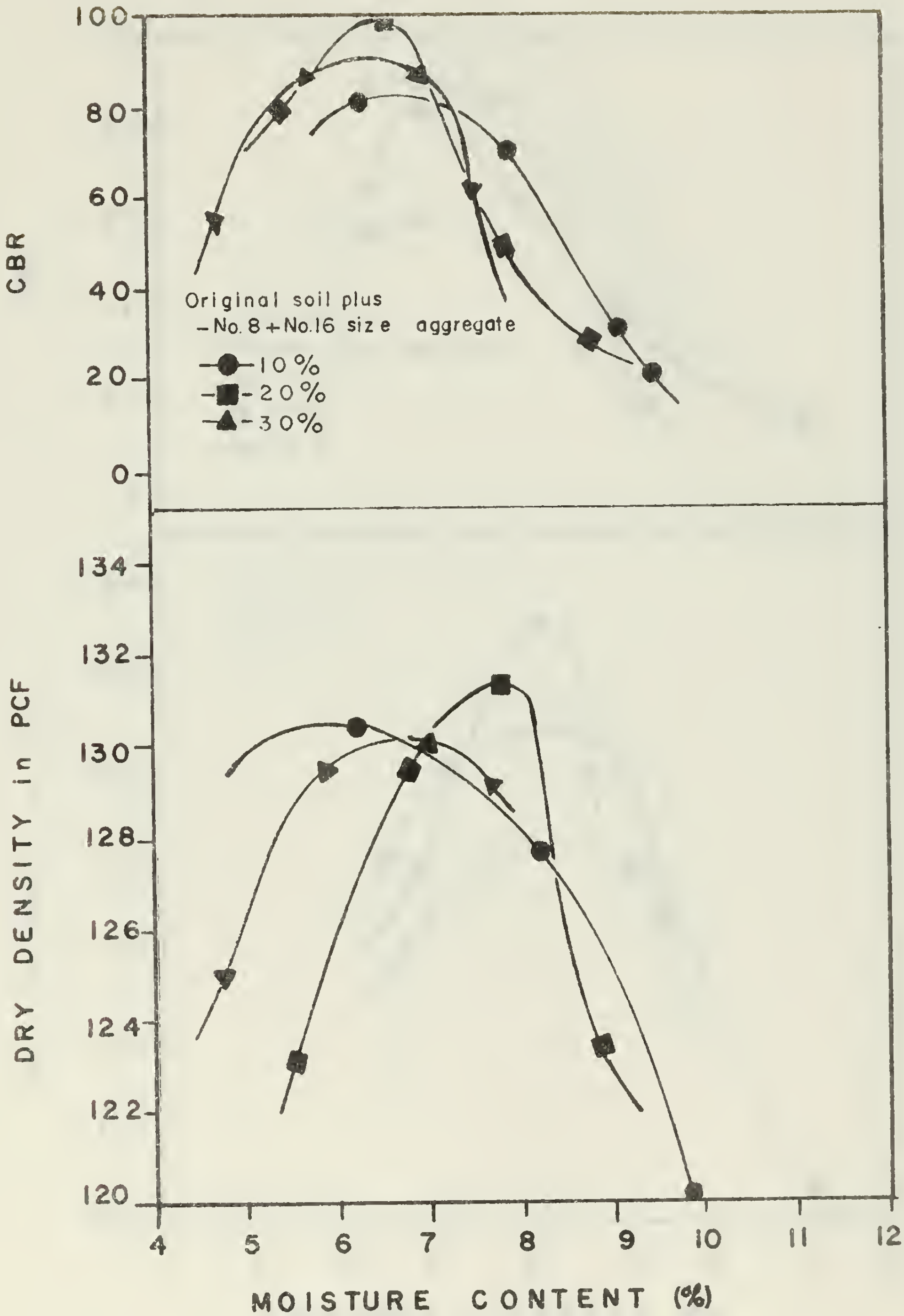
ORIGINAL SOIL WITH LARGE AGGREGATE ADDED

FIGURE 7.9e

of aggregate added. As shown, the densities obtained (compared to that of the original soil) were not greatly improved with the addition of any of the amounts or size of aggregate added.

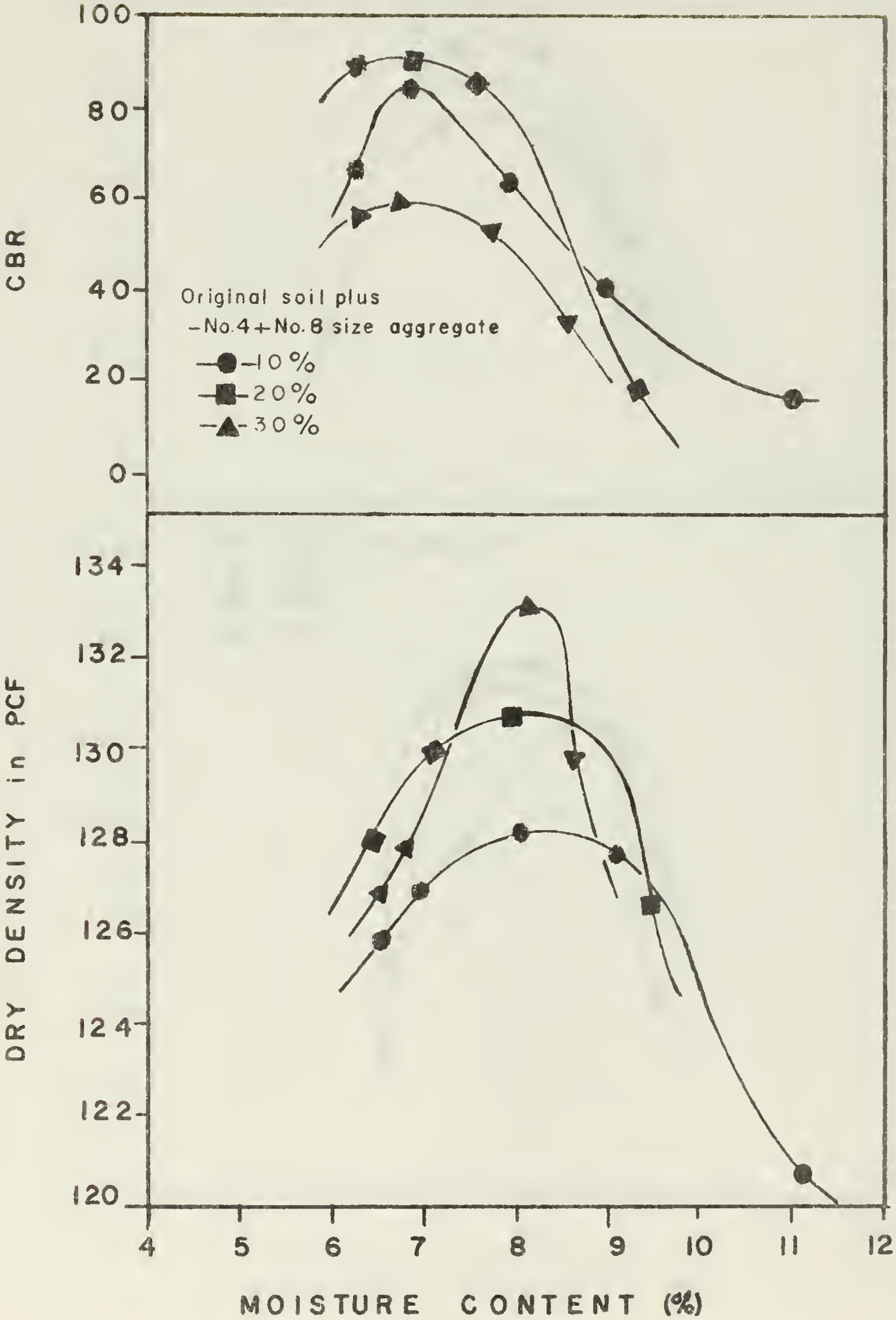
CBR test results

The results of the addition of each size aggregate for each of the percentages added to alter the natural soil are shown in figures 7.10a to 7.10e. The addition of 20 percent of each of the large size aggregates to the natural soil increased the CBR values greater than the other two percentages considered and, for a range of moisture content of 6 to 8 percent produced CBR values in excess of 80. For the addition of 10 and 30 percent aggregate the CBR values were not substantially increased above that of the natural soil. The maximum density and CBR values for each size and percentages were plotted in figure 7.11. For each percentage of aggregate added, the same curve resulted, no matter which size aggregate was considered, i.e., 10% of -4 to +8 size added produce the same curve as when 10% of -3/8 to +4 size was added, etc. Therefore, within limits, the amount of larger size aggregates added rather than the size added, had the most effect on the stability of the resulting mixture. Figure 7.12 shows that when maximum CBR and density values from figure 7.11 were plotted against the percent aggregate added, 12 to 17 percent aggregate proved to be the optimum range of material to be added.



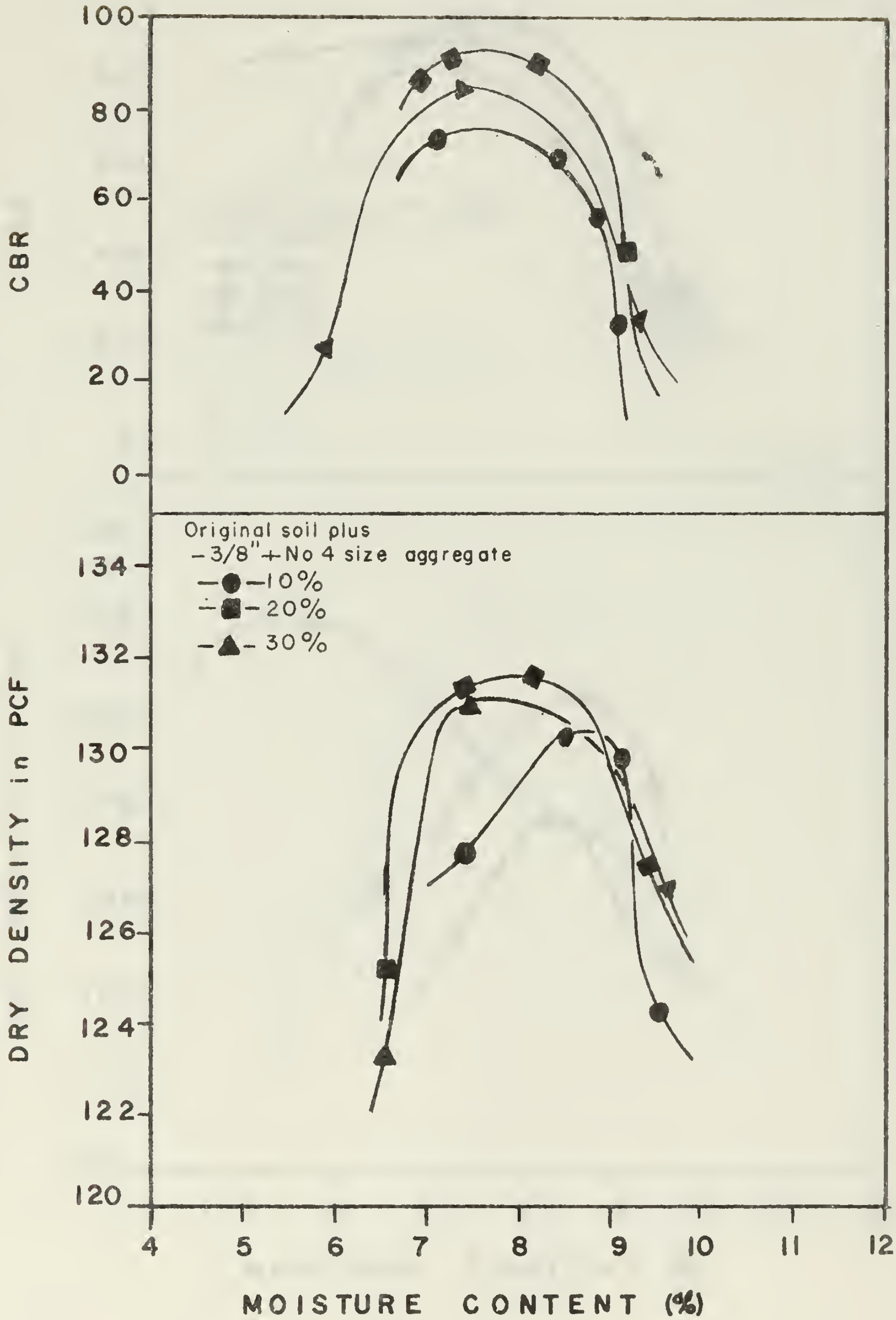
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.10A



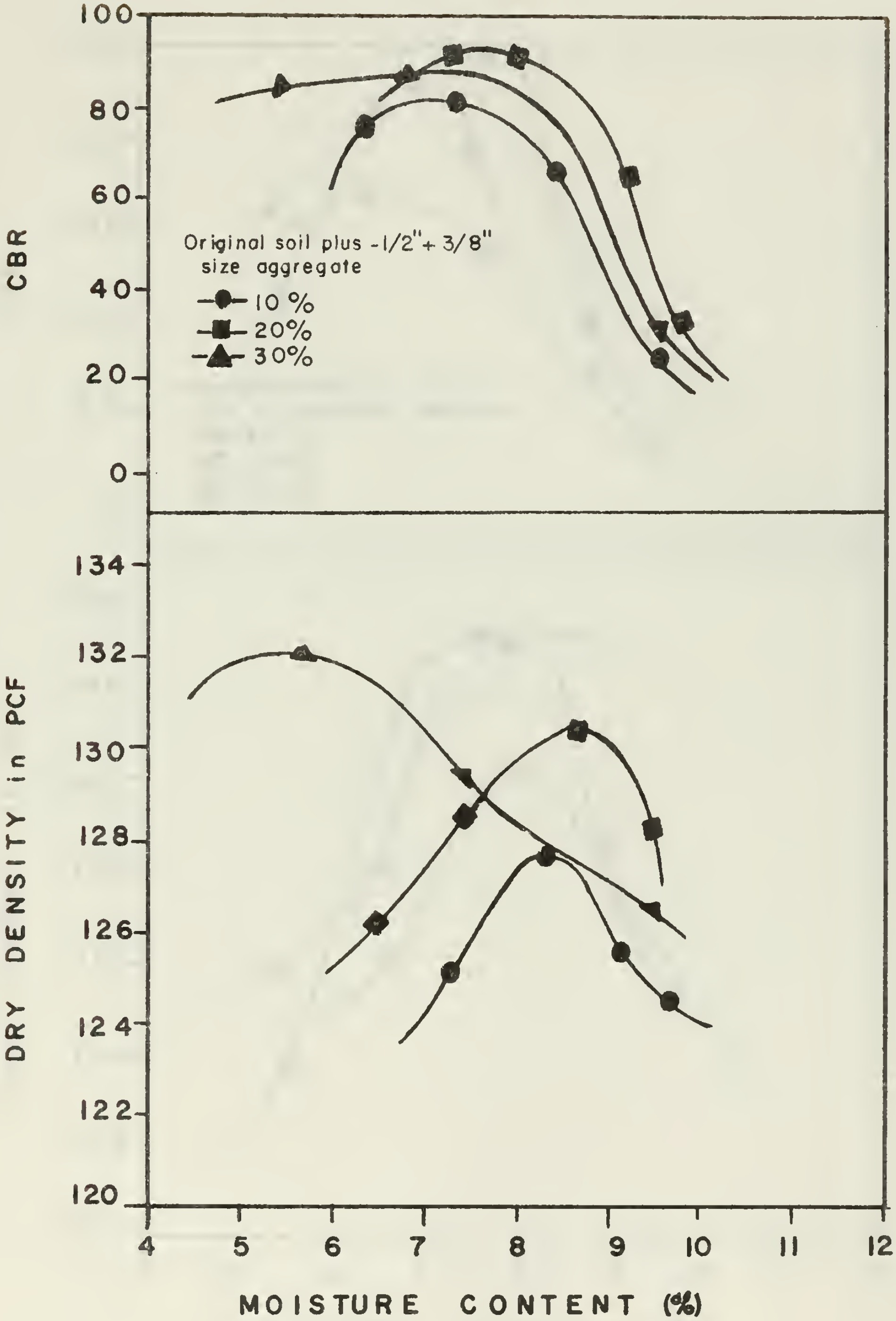
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.10B



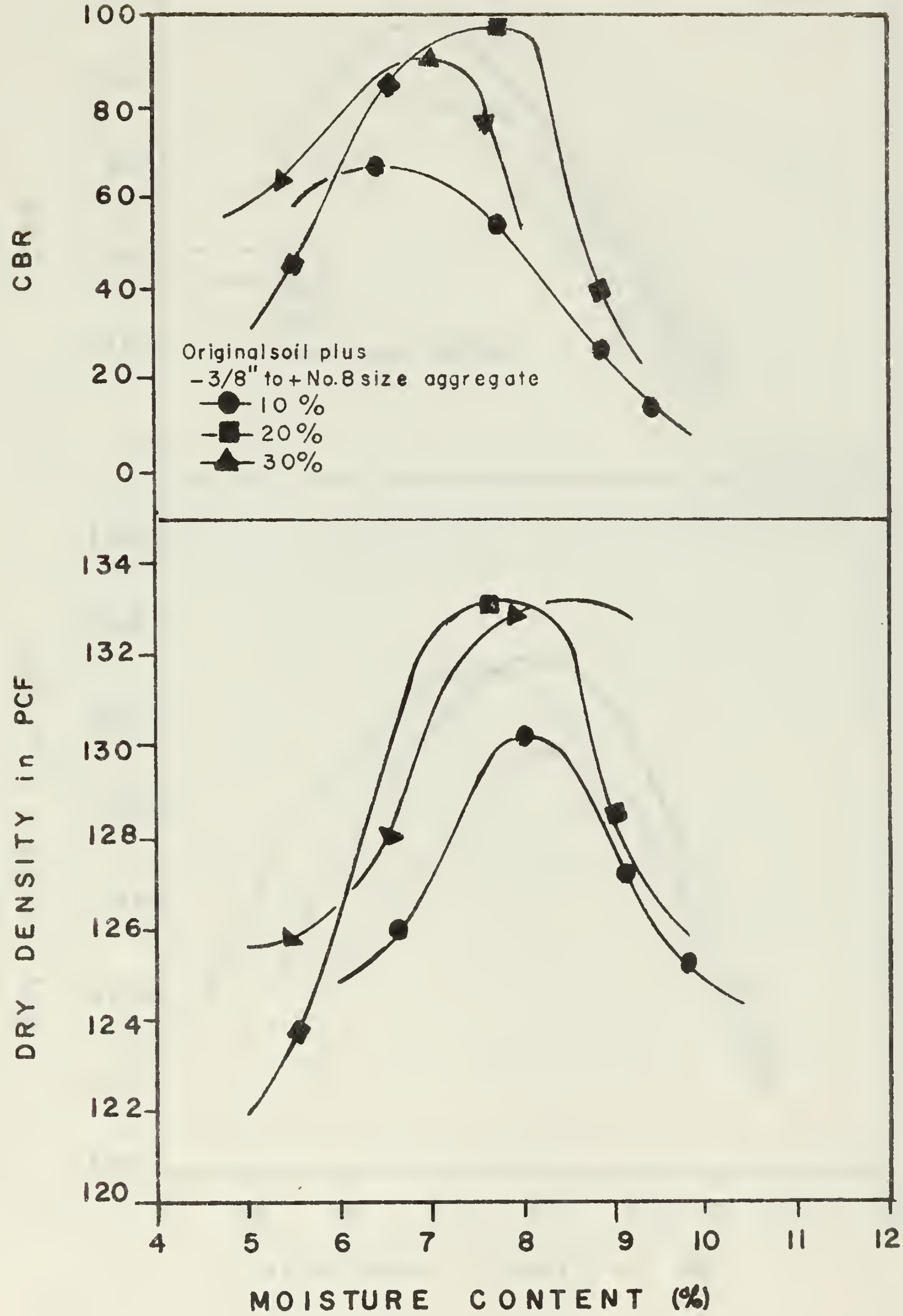
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.10c



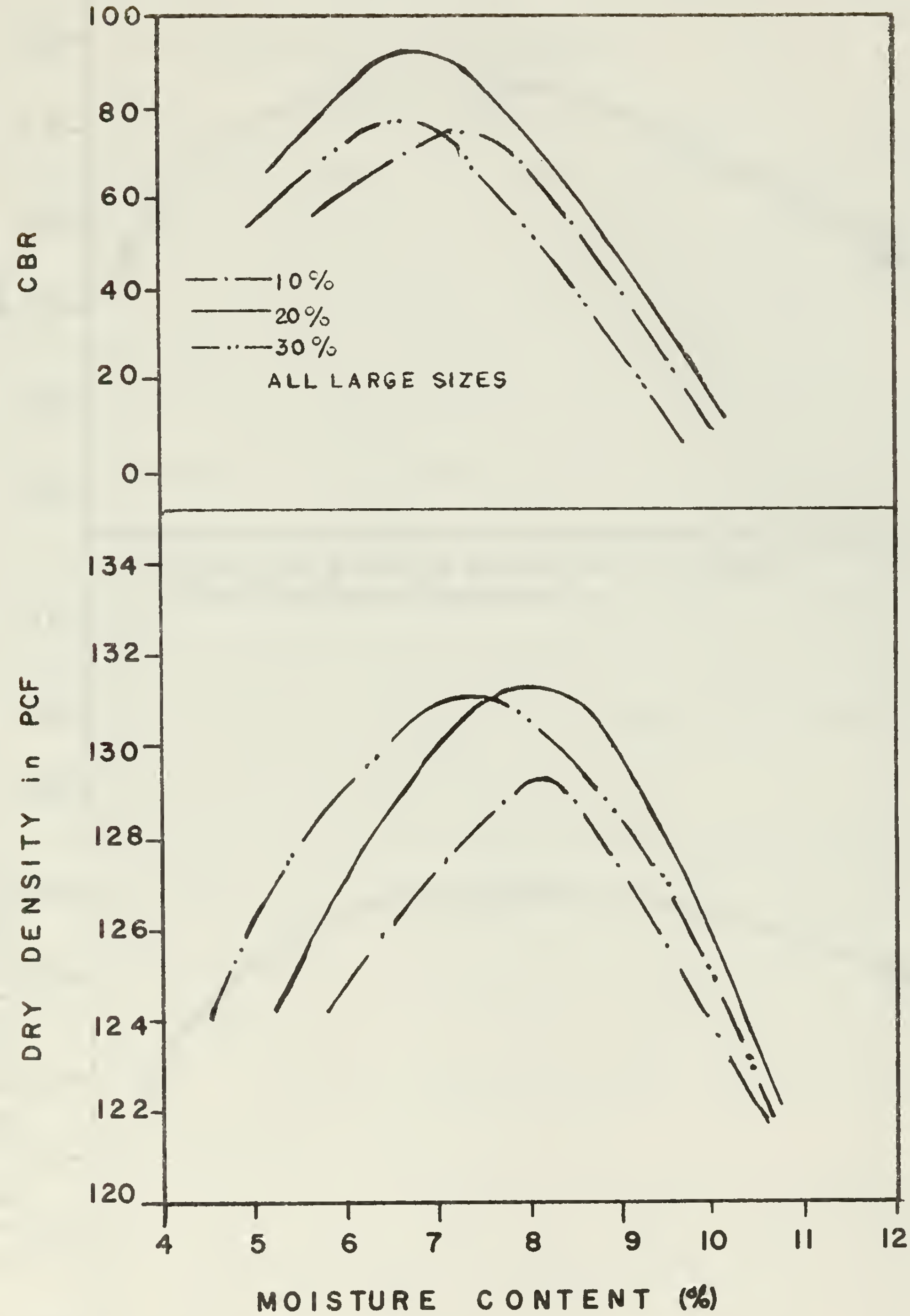
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.10D



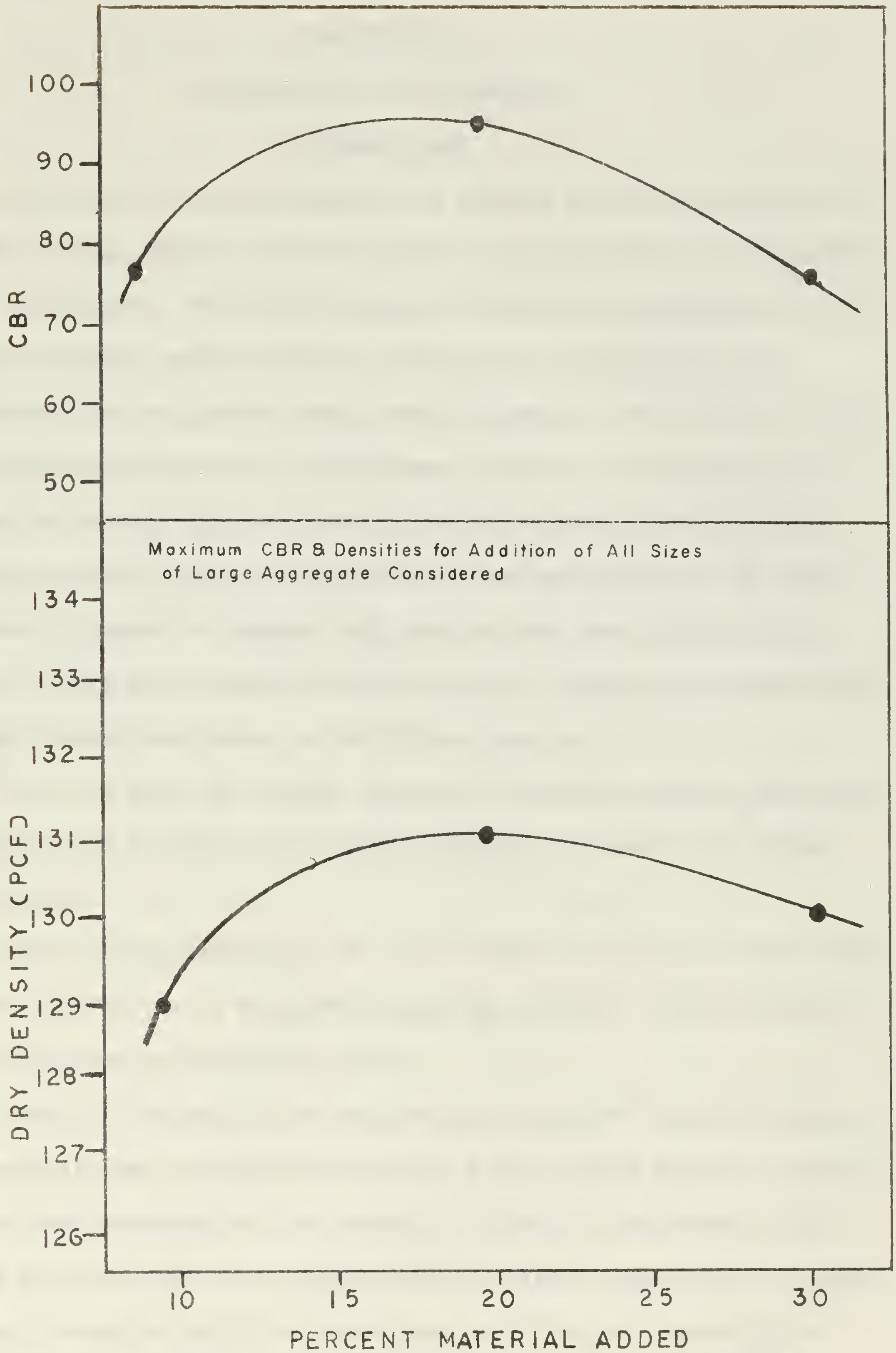
MOISTURE-DENSITY-CBR RELATION

FIGURE 7.10E



MOISTURE-DENSITY-CBR RELATION

FIGURE 7.11



(%) AGGREGATE-DENSITY-CBR RELATION

FIGURE 7.12

CHAPTER VIII

DISCUSSION OF TEST RESULTS

Original Soil

The location of the deposit with respect to the composition and the historical geologic events indicate why the material is classified as a silty-sand. The particle shape (subangular to rounded) and the type of mineral grains (quartz) indicate that the material was weathered from an igneous rock, probably granite, and transported for a considerable distance to its present position. The silt and clay sizes in the soil probably result from the weathering of shale formations exposed during the formation of the geosyncline. The small amounts of feldspars present help substantiate the origin of the quartz from granite and also show the time of leaching and weathering of the transported grains to be of long duration.

The fact that the mineral grains are primarily quartz, which has a hardness of 7 (Mohs scale), would indicate the grains are strong and durable.

The small difference in the liquid limit and plastic limit values (PI=0) coupled with a relatively large percentage of fines indicates that the fines are relatively inert.

Based on the grain-size distributions and AASHO specifications, the material was unsuitable for use as a base course material because of the over-abundance of fine material. The size and amount of the fines indicate that the material would be highly susceptible to frost action, caused by capillary water, and would not be acceptable as a base for rigid pavement because of pumping under load and moist conditions.

The CBR values of the unaltered soil were considerably higher than expected. The high quantity of fines seemed to indicate a soil-aggregate mixture wherein the grain-to-grain contact of the larger particles would be destroyed. (Type c fig. 2.1). However, the PI of the mixture porved the finer fraction to be relatively inert. Since the PI was approximately zero and there existed a small size differential between the largest and smallest grains, the CBR value tended to be higher than expected.

Thus the relatively high value of CBR (70) and density are attributed to the durability of the grains, inertness of the fines and the confining pressure applied by the test cylinder walls. When the sample was extended from the mold, after soaking and penetration, the surface showed a high degree of cracking and when subjected to a small pressure by hand, crumbled. This would indicate that the material would serve satisfactorily as a subbase and subgrade material for flexible pavements, only if both components are properly compacted and if the subbase is confined laterally by the use of adequate shoulders.

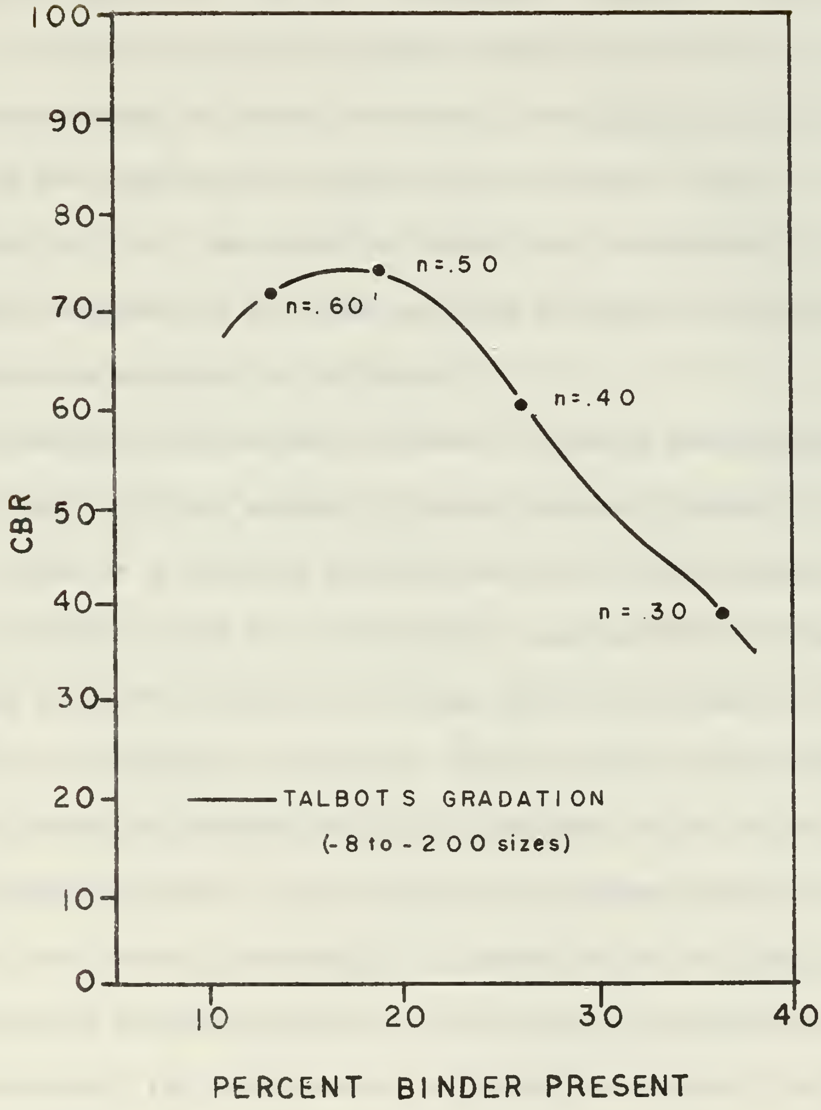
Talbot's Gradation

Talbot's gradation produced a grain-size distribution that met AASHO grading requirements for base course material. Talbot's equation required a greater quantity of the larger size particles (-8 to +16 size) than the original soil, thereby producing an acceptable AASHO gradation. The plasticity index of the Talbot's gradations increased over that of ~~the~~ original soil because of the clay slurry added to produce the required gradation.

The maximum densities obtained by Talbot's gradations were lower than that obtained for the original soil. Talbot's gradations for this soil contained a larger binder content than the original soil, producing a grading similar to that shown in figure 2.1c. However, the larger grains were separated more producing a lower density.

Based on strength characteristics, modification of the original soil gradation by the use of Talbot's equation for the addition of all particle sizes from the largest size in the sample (+#8) to the smallest particle present (-#200), did not substantially increase the stability of the soil and, for some values of 'n', actually decreased the penetration resistance. In order to determine why this modification did not substantially improve the strength of the soil, the results of the modification in view of the factors affecting the strength characteristics must be considered.

As stated previously, the ratio of binder to aggregate is one factor that determines strength characteristics of soil-aggregate mixtures. The percentage of material passing the No. 200 size sieve, which is an indirect measure of the binder to aggregate ratio, shows that for high percentages (low 'n' values) of binder the CBR values are relatively low, while for small percentages ('n' values = 0.50, 0.60) the CBR values were correspondingly higher. Therefore, as shown in figure 9.1, as the percentage of binder (-#200 size material) decreased the CBR value increased until n=0.60 when the binder to aggregate ratio became too low and the CBR value began to decrease. Thus, the optimum gradation occurred at n=0.50. Stated in terms of the Plasticity Index (PI), as the PI of the various gradations decreased, the strength to resist penetration increased.



BINDER-CBR RELATION

FIGURE 9.1

The reason why the optimum value of 'n' equaled 0.50 can be established by examining the grain-size distribution in view of the possible physical states (fig. 2.1) of soil-aggregate mixtures. For high percentages of binder, the aggregate "floats" in the matrix (fig. 2.1c) and the grain-to-grain contacts were not established. As the percentage of binder decreased, the aggregate grains began to touch and some grain-to-grain contact began. When 'n' reached the value of 0.60, the amount of binder was insufficient to fill the voids completely, and some particle slippage occurred that resulted in a decrease in CBR value.

It should be noted that in order to obtain the optimum physical state (fig. 2.1b) the amount of binder required depends on the void ratio, which is a function of the size of the constituent particles in the mixture. That is, if there are many particles of approximately the same size, the voids will be high and a great deal of binder is required to completely fill them. When a load is then applied, the mixture undergoes plastic deformation which results in decreased penetration resistance. Even though the optimum amount of binder is present, the overall percentage of binder may be too large, as compared with another gradation, resulting in decreased strength.

Therefore, the satisfaction of Talbot's equation for the entire range of particle sizes within the samples considered produced a mixture which required a high optimum binder content, thereby creating low penetration resistance.

<u>Modified Talbot's Gradation</u>

The modified Talbot's gradation procedure illustrated the importance of a low optimum binder content. Although the optimum amount

of binder required by the modified Talbot's equation was less than the optimum binder content required by the unmodified equation, higher CBR values were obtained.

The effect of the various particles within the sample can be obtained by inspection of the corresponding CBR values. The effect of the binder was discussed above. The CBR values of the mineral filler size (-#16 to +#50 size) indicate that as long as some of the material is present in the sample to help fill the void space, the exact percentage is relatively unimportant. The purpose of the intermediate size particles is to fill void space. These sizes provide little strength themselves because the larger particles provide grain-to-grain contact thereby bridging the middle sizes. However, they are important because their presence reduces the amount of binder required to fill the void space. Since the particles are small, the gradation within the range of sizes is relatively unimportant. Although their densities are less than those for samples associated with the addition of binder, the strength is greater because of the reduction in plasticity.

The amount of the larger size particles present, however, is important as shown by the CBR values. Since the size of the grain-to-grain contact area changes greatly with the amount of +#10 size aggregate present, higher CBR values would be expected when the binder to aggregate ratio decreases, provided of course, the binder content is high enough to provide a dense mixture with little plasticity.

Addition of Large Size Aggregate

The effect of adding different amounts of large size aggregate can also be explained in terms of the binder to aggregate ratio. Within the range of sizes tested, no matter what maximum size aggregate

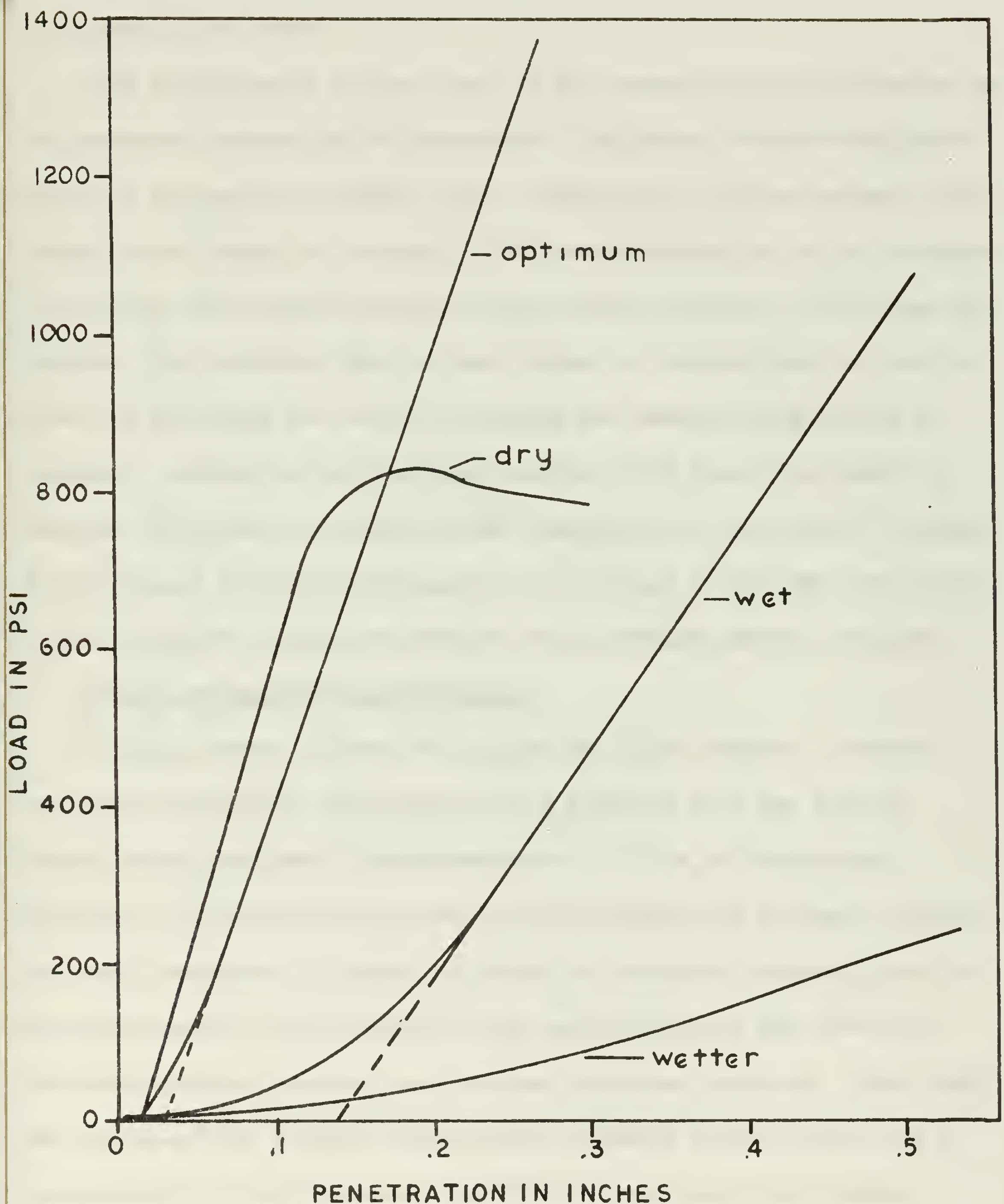
was added the CBR values tended to show a peak value when approximately 12 to 17 percent of aggregate was added. Generally, maximum density occurred at this percentage also indicating that the optimum physical state for the soil-aggregate mixtures were approached. For percentages less than the 12-17 percent range, the large grains 'floated' within the binder. For percentages greater than the 12-17 percent range, the larger grains were not bound together completely. The slight difference in the maximum CBR value obtained for the various sizes is attributed to the differences in various particle shapes. For the combination of sizes the amount of aggregate added, rather than the size, appeared to be the more important. This would have to be confirmed by further tests.

General Observations

During the progress of this paper several general observations were made regarding stabilization of a granular soil by mechanical means.

CBR correction procedure

Figure 9.2 shows a typical set of load-penetration, CBR correction curves (not corrected to the origin). It is interesting to note that for this granular soil various curves show characteristic shapes for different moisture contents at the time of compaction. For moisture contents on the wet side of optimum, the curves were concave upward, the amount of concavity increasing with greater moisture contents, while those compacted at moisture contents less than optimum rose sharply, but soon curved concave downward. For samples very close to, or at, the optimum moisture content the curve approached a straight line. The correspondence between the shapes of the CBR correction



TYPICAL CBR CORRECTION CURVES

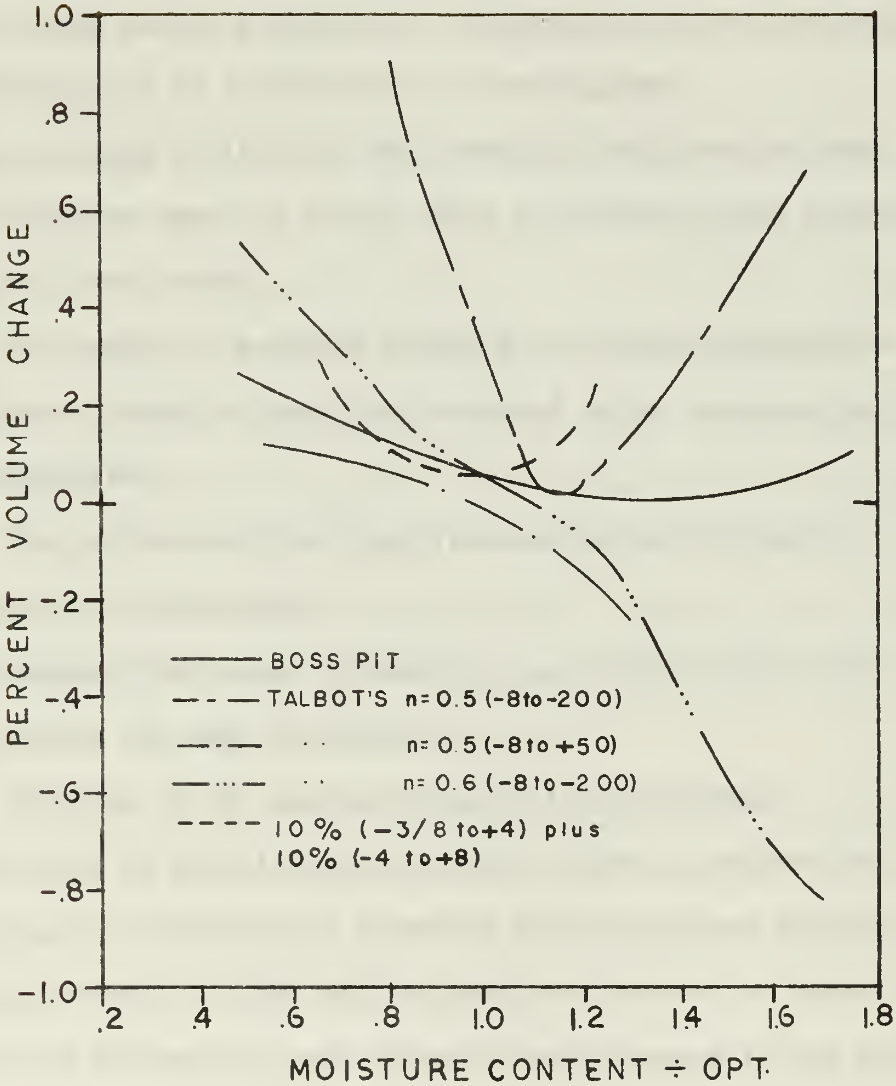
FIGURE 9.2

curves and the moisture content relative to optimum, occurred for 175 CBR penetration tests.

The significance of the shape of the correction curve relative to the moisture content may be important. The shape of curve indicates where on the moisture-density curve (relative to optimum values) the sample being tested is located. This same information can be obtained by plotting the moisture-density relationship directly. There may be, however, the advantage that a fewer number of samples need be run in order to determine how close to optimum the sample being tested is located. However, since the test requires four days, the number of samples tested may be insignificant compared with the time of testing. Further study of the significance of the shapes of the CBR correction curves relative to moisture-density relationships appears warranted.

Shrink and swell characteristics

Granular soils seldom are plagued by volume change. However, the moisture-density relationship of a granular soil may greatly effect shrink and swell characteristics. If the soil-aggregate mixture is compacted at moisture contents other than optimum, shrink and swell may occur. Figure 9.3 shows for the soil studied, that for moisture contents below optimum some swell did occur and that for moisture contents greater than optimum shrinkage occurred. Both swell and shrinkage can produce differential pavement movement that can be detrimental to the structural stability of the completed roadway. Since maximum CBR values do not always occur at optimum moisture-density contents, volume change of pavement components must be considered and accounted for before changing moisture contents to obtain maximum CBR values.



SHRINK-SWELL CHARACTERISTICS

FIGURE 9.3

Practical limits of Talbot's formula

Talbot's formula indicates the desired grain-size distribution for obtaining high density. However, one must consider the practicality of using Talbot's gradation. The range of sizes over which the equation is to be applied must be investigated.

The following limitations were observed while working with Talbot's formulas when the entire range of particle sizes within the original soil were added.

1. The amount of material required to satisfy the equation for the entire range of particles contained in the original soil may be considerable.

2. The addition of the finer fraction may be difficult, impractical and unnecessary.

3. Maximum CBR values obtained did not coincide with the maximum density for many gradations.

4. Batching of the aggregate may be time consuming.

The amount of material that should be added to achieve the Talbot gradation may be considerable depending upon the parent material grain-size distribution. For the soil studied satisfaction of Talbot's gradation for the entire range of particles contained in the original soil required the addition of more than 50% aggregate for all values of 'n' considered. It is important to note that only addition of material was considered. For certain grain-size distributions removal of some sizes could be an effective means of reaching the Talbot gradation, but for most grain-size distributions the removal of any particle sizes is impractical.

For the finer fraction, the grain-size distribution of the portion passing the #200 sieve is generally not specified. If material is to be added to that portion, the practicality of how this is to be accomplished becomes important. Clay material passes the #200 sieve, however, clay is very difficult to add. Specifications limit the percentage of clay that may be added by specifying the allowable plasticity index. Clay minerals have been added in slurry form, but the amount of clay that goes into solution is very difficult to control and would be impractical with the equipment now available.

Figure 7.7a shows the relation between values of 'n', density and CBR values. For several samples the optimum density was comparatively low while the corresponding CBR value obtained was relatively high and vice versa. Thus, although Talbot's formula gives a method of obtaining high densities for various gradations, there is not always a direct correlation with CBR values.

If Talbot's formula is used for soil stabilization the proper amounts of each size aggregate would have to be mixed with the soil. An aggregate batch plant would probably be necessary to accomplish the mixing of the additives with the soil.

The above limitations are stated as observations made when Talbot's equation was applied as a continuous function for the entire range of sizes contained in the sample. This does not prove that the equation could not be used for several widely separated points on the gradation curve. Each soil tested would have to be investigated for this possibility. However, it is the opinion of the author that Talbot's equation should be confined for use in determining aggregate

gradations for concrete and bituminous mixtures, the purpose for which the equation was intended by Mr. Talbot.

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the findings of this study, the following specific conclusions appear to be warranted:

(1) The silty-sand (Boss Pit) material used in this study is unsatisfactory, based on gradation and CBR value, in the untreated state as a base course material. However, it does meet the requirements as a subbase material for lower type pavement construction, with the application of 95% Modified AASHO compactive effort. The principal defect of the soil is the over-abundance of finer materials (minus #200 size), coupled with the absence of large size aggregate (plus #8 size).

(2) Compactive effort alone, even that of Modified AASHO, is not sufficient to achieve the required strength and stability properties for use as a base course material.

(3) The optimum value of 'n', based on maximum density and CBR, used to satisfy Talbot's equation for all combinations of sizes and amounts added, was 0.50.

(4) The use of Talbot's formula for modifying the soil gradation by the addition of particles including clay sizes did not upgrade the soil enough for its use as a base course, nor does the increase in strength warrant the quantity of material added.

(5) The satisfaction of Talbot's equation, for increasing minimum 'd' values greater than the #200 size, did upgrade the soil-aggregate mixture adequately enough for its use as a base course material (CBR=80). However, the inconsistency between maximum density and CBR

values obtained, and the amount of material necessary to satisfy the equation for the results derived, indicate that Talbot's equation applied as a continuous function, does not economically achieve the desired properties for this soil.

(6) The addition of large size particles (minus #8 plus #16 to -1/2" plus 3/8" sizes) improved the soil's strength and stability characteristics enough for use as a base course for all sizes when 12 to 30 percent of material was added, the highest value of CBR occurring at approximately 17%.

(7) A combination of larger size particles (5% each of -4+8 and -3/8 +4 sizes) also improved the soil-aggregate mixture properties for use as base course material, however, since the same amount (17%) was required to achieve approximately the same strength and stability characteristics and since the process of combination requires more mixture control, the use of man-made particle mixtures is not warranted. Natural occurring aggregate mixtures, containing these larger sizes, could be used satisfactorily and economically, however.

Recommendations

Based on the findings of this research project, the following recommendations are proposed:

(1) The Boss Pit silty-sand should be considered for use as a subbase material for flexible pavement construction when proper compactive effort is applied. Pumping or blowing would probably result if the parent material were used as a base material for rigid pavements.

(2) The silty-sand material should be considered for use as a base course material when adequately stabilized. Stabilization by the

addition of 15% large size aggregate (plus #8 size) would be economically feasible when the hauling costs remained low. The use of unprocessed, pit-run aggregate would provide stability at a minimum cost.

(3) Talbot's formula should be used only as a guide for achieving mechanical stabilization of a granular soil, and subsequent stabilization by mechanical means should be based on the grain-size distribution, the relative amounts of fine and maximum size particles, and the plasticity of the parent material. The following procedure for subsequent granular soil stabilization is recommended:

1. Plot the grain-size distribution of the soil considered and that of the specification used. Compare these curves to determine deficiencies in the soil's grain-size distribution.

2. Make Atterberg Limits tests to determine plasticity of the soil. Check the relative binder to aggregate content.

3. Add those sizes determined to be deficient by steps 1 and 2 above in small percentage increments. Test resulting gradations for density and stability. Determine the optimum gradation from these tests.

(4) Stabilization by use of admixtures should be investigated for this soil.

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APPENDIX

SUMMARY OF DATA

Classification and Mineral Composition
(from Chapter VI)

The Boss Pit silty-sand tested in this project can be classified according to several standard systems as follows:

Classification System	
AASHO	A-2-4(0)
Unified	SM Silty-Sand
Civil Aeronautics Administration	E-3
USDA Textural	Sand
Casagrande	SF Sand with Fines
Colo. Hgwy. Dept.	

The mineral composition of the material studied consisted primarily of subangular quartz minerals with small amounts of fine chert and feldspar grains, some organic material, and approximately 24% silt and clay sizes.

Atterberg Limit Test Results
(from Chapter VII)

Gradation	LL(%)	PL(%)	PI(%)
Original Boss Pit	18.0	19.2	≈0.0
Minus #200 sizes added	66.8	31.9	34.9
Talbot's gradation (for entire range of sizes added)			
n=0.30	20.5	12.03	7.49
n=0.40	14.0	12.86	1.14
n=0.50	14.9	13.07	1.83
n=0.60	13.9	14.10	≈0.00

Grain Size Distributions

Sieve Number or Screen Size	Boss Pit	Percent Passing Talbot's Equation n= 0.30	0.40	0.50	0.60
Talbot's Equation (-#8 to -#200)					
No. 8	100.0	100.0	100.0	100.0	100.0
No. 16	96.9	84.4	79.5	75.1	70.9
No. 30	79.8	68.1	60.0	52.8	46.4
No. 50	55.1	55.6	45.6	37.6	30.9
No. 100	33.2	45.2	34.7	26.6	20.4
No. 200	24.8	36.5	26.1	18.6	13.4
Talbot's Equation (-#8 to +#100)					
No. 8		100.0	100.0	100.0	100.0
No. 16		84.4	79.5	75.1	70.9
No. 30		68.1	60.0	52.8	46.6
No. 50		55.6	45.5	37.6	30.9
No. 100		15.8	16.5	16.7	15.9
No. 200		11.8	12.3	12.5	11.9
Talbot's Equation (-#8 to +#50)					
No. 8		100.0	100.0	100.0	100.0
No. 16		84.4	79.5	75.1	70.9
No. 30		68.1	60.0	52.8	46.4
No. 50		26.2	27.4	27.7	26.4
No. 100		15.8	16.5	16.7	15.9
No. 200		11.8	12.3	12.5	11.9
Talbot's Equation (-#8 to +#30)					
No. 8		100.0	100.0	100.0	100.0
No. 16		84.4	79.5	75.1	70.9
No. 30		37.9	39.7	40.1	38.2
No. 50		26.2	27.4	27.7	26.4
No. 100		15.8	16.5	16.7	15.9
No. 200		11.8	12.3	12.5	11.9
Talbot's Equation (-#8 to +#16)					
No. 8		100.0	100.0	100.0	100.0
No. 16		46.0	48.2	48.7	46.4
No. 30		37.9	39.7	40.1	38.2

Grain Size Distribution

Sieve Number or Screen Size	Percent Passing n=0.30	0.40	0.50	0.60
No. 50	26.2	27.4	27.7	26.4
No. 100	15.8	16.5	16.7	15.9
No. 200	11.8	12.3	12.5	11.9
Large Sizes Added	10%	15%	20%	30%
(-#8 to +#16)				
No. 8	100.0		100.0	100.0
No. 16	86.9		76.9	66.9
No. 30	71.8		63.8	55.7
No. 50	49.7		44.2	38.6
No. 100	29.9		26.8	23.2
No. 200	22.3		19.8	17.3
(-#4 to +#8)				
No. 4	100.0	100.0	100.0	100.0
No. 8	90.0	85.0	80.0	70.0
No. 16	87.3	82.3	77.5	67.6
No. 30	71.8	67.8	63.8	55.7
No. 50	49.7	46.8	44.2	38.2
No. 100	29.9	28.2	26.8	23.2
No. 200	22.3	21.1	19.8	17.3
(-#3/8 to +#4)				
No. 3/8	100.0	100.0	100.0	100.0
No. 4	90.0	85.0	80.0	70.0
No. 8	90.0	85.0	80.0	70.0
No. 16	87.3	82.3	77.5	67.6
No. 30	71.8	67.8	63.8	55.7
No. 50	49.7	46.8	44.2	38.6
No. 100	29.9	28.2	26.8	23.2
No. 200	22.3	21.1	19.8	17.3

Grain Size Distribution

Sieve Number or Screen Size	Percent Passing 10%	15%	20%	30%
(-#1/2 to +#3/8)				
No. 1/2	100.0		100.0	100.0
No. 3/8	90.0		80.0	70.0
No. 4	90.0		80.0	70.0
No. 8	90.0		80.0	70.0
No. 16	87.3		77.5	67.6
No. 30	71.8		63.8	55.7
No. 50	49.7		44.2	38.2
No. 100	29.9		26.8	23.2
No. 200	22.3		19.8	17.3
(-#3/8 to +#8)				
No. 3/8	100.0		100.0	100.0
No. 4	95.0		90.0	85.0
No. 8	90.0		80.0	70.0
No. 16	87.3		77.5	67.6
No. 30	71.8		63.8	55.7
No. 50	49.7		44.2	38.6
No. 100	29.9		26.8	23.2
No. 200	22.3		19.8	17.3

Moisture-Density-CBR Relations
(from Chapters VII)

Gradation	Moisture (%)	Density (pcf)	CBR
Original Boss Pit	6.58	123.9	70.5
Talbot's gradation			
(-#8 to -#200)			
n=0.30	8.23	129.6	38.0
n=0.40	6.83	120.8	59.0
n=0.50	7.38	129.7	73.0
n=0.60	7.26	130.5	72.6
(-#8 to +#100)			
n=0.30	6.85	127.0	92.8
n=0.40	7.79	128.5	91.8
n=0.50	6.54	129.5	90.0
n=0.60	5.58	127.4	82.5
(-#8 to +#50)			
n=0.30	7.34	127.0	81.3
n=0.40	6.80	128.0	82.5
n=0.50	6.34	127.7	80.0
n=0.60	6.58	129.7	91.5
(-#8 to +#30)			
n=0.30	6.66	127.5	77.3
n=0.40	5.53	126.0	78.5
n=0.50	6.96	133.5	88.5
n=0.60	5.49	126.0	78.5
(-#8 to +#16)			
n=0.30	5.45	126.5	71.6
n=0.40	7.13	131.0	65.0
n=0.50	6.50	134.5	92.5
n=0.60	6.87	134.0	85.7
Large sizes added			
(-#4 to +#8)			
10%	6.99	127.0	81.0
15%	7.44	128.5	94.5
20%	6.46	128.5	88.5
30%	6.63	127.0	57.5
(-#3/8 to +#4)			
10%	7.81	127.0	75.0
15%	7.55	128.5	102.0
20%	8.07	131.8	90.0
30%	6.80	131.0	83.7

Moisture Density-CBR Relations

Gradation	Moisture (%)	Density (pcf)	CBR
Large sizes added			
(-#1/2 to +#3/8)			
10%	8.32	127.5	90.0
20%	7.67	128.4	80.0
30%	7.27	127.0	86.0
(-#8 to +#16)			
10%	6.66	130.4	78.5
20%	6.68	129.9	98.0
30%	6.99	130.4	85.0
1/2(-#3/8 to +#4)			
1/2(-#4 to +#8)			
10%	6.77	126.0	65.5
20%	7.57	133.5	104.8
30%	7.18	128.0	90.5